ELEMENTARY ZOOLOGY

FOR MEDICAL STUDENTS

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BY

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PREFACE

THIS book has been prepared for the use of students who need an account of the types which are studied in preparation for First Medical Examinations. It contains neither the appendix upon practical work, the descriptions of internal and external parasites and various other invertebrata, the vertebrate morphology, nor much of the general matter comprised in my *Manual of Zoology*, from which, with certain alterations and omissions, the bulk of its pages are drawn. The introductory chapter has been rewritten.

L. A. BORRADAILE.

SELWYN COLLEGE, CAMBRIDGE,
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which is contained from the first in the substances which are broken down. This happens, for instance, in many parasitic animals and plants, and in others which live in situations in which they cannot obtain free oxygen. Thus the Yeast Fungus, living in solutions which contain no dissolved oxygen, breaks down the sugar glucose according to the following equation :

$$\underset{\text{(Glucose)}}{C_6H_{12}O_6} = \underset{\text{(Alcohol)}}{2C_2H_6O} + 2CO_2$$

Animals and plants which so obtain their energy are said to be *anaerobic*. Since the substances to be broken down never contain enough oxygen to oxidise all their carbon and hydrogen, this procedure is wasteful. Usually, however, the combined oxygen is supplemented by some which is taken in from without the body, in the free condition, to complete the process, which is thus a *combustion*. The beings in which this takes place are said to be *aerobic*. The obtaining of free energy, by the disintegration of complex substances is familiar to us in various processes employed by man. Thus the energy imparted to a bullet by an explosive is liberated by an internal process comparable to that of anaerobic animals and plants. The energy of a petrol or steam engine or the light of a candle is obtained by the use of oxygen from the air in combustion, much as it is in aerobic beings.

It is not difficult to prove that this disintegration is taking place in the body. Since the molecules which break down often contain, besides carbon, hydrogen, and oxygen a good deal of nitrogen, the products of their disintegration include, besides carbon dioxide and water, certain fairly simple compounds of nitrogen, such as urea, $CO(NH_2)_2$. (1) The intake of oxygen and loss of carbon dioxide during life are easily demonstrated. Men or animals enclosed in a vessel to which air has not access are unable to live for more than a short time. The animals are stifled, just as a fire or the flame of a candle may be stifled, by want of air, and subsequent examination of the gases in the vessel will show that the oxygen has been depleted and replaced by carbon dioxide, just as it would be if a candle had been burnt in it. This loss

of carbon dioxide and the intake of oxygen which usually accompanies it are characteristic of living animals and are known as *Respiration*. In man and animals like him, it takes place through the lungs, in breathing. If the breath be tested, it will be found to have undergone the same changes as the air in a vessel in which an animal has been stifled. Fishes and other aquatic animals use the oxygen which is held in solution in the water in which they live. (2) The nitrogenous waste matters may be identified in the urine by chemical analysis. (3) The formation of water is less easily demonstrated, because the bulk of the water lost to the body has been taken in as such through the mouth to perform certain indispensable functions, one of which is the washing out of the nitrogenous waste, but a careful comparison of the quantities of water which enter and leave the body shows that more goes out than can be accounted for by what has entered.

Appearance of the liberated energy in various forms.

The energy freed in the disintegration of the body-substance appears, as we have seen, in various ways. The most characteristic and important of these are contraction, chemical work, excretion, secretion, and possibly the conduction of impulses. *Contraction* is the process by which mechanical movements are carried out. In it a portion of the living substance changes in shape but not in size, growing shorter in one direction but thicker in others. This may easily be felt in the working of any of the great muscles of the human body, as when the well-known "biceps," in shortening to pull up the forearm, grows at the same time thicker. Instances of *chemical activity* are seen in the formation of the constituents of the many juices which are used for various purposes in the body. Thus the "gastric juice," by which food is digested and disinfected in the stomach, contains among other substances hydrochloric acid, whose formation in face of the alkalinity of the blood involves very considerable chemical work. Other examples of liquids formed for special purposes are the spittle or saliva which helps in the swallowing and digestion of food, tears which wash clean the surface of the eyes, and so forth. The regions in which materials are thus formed are known as *glands*. Lastly, a part of the energy liberated in the

body is used in the removal from the substance of the body of the chemical products of its activity. We have seen that in the process of disintegration there arise waste products of which the body gets rid. We have just seen also that certain of its actions consist in the chemical manufacture of materials which are not purely waste but have their uses to the body. The casting out from the substance of the glands of the materials formed in these two cases, and of the water in which they are dissolved, is a necessary part of the working of the bodily machine. The waste products are got rid of because they are poisonous, and the products of chemical manufacture are removed in order to be of use elsewhere. Both kinds of material are accordingly shed, sometimes upon the surface of the body, but usually into vessels which conduct them to the required locality. This shedding out is a distinct process, carried on by an exercise of the activity of the living substance of the body. No real distinction can be drawn between the two cases, but the process is called *excretion* when the substances cast out are purely waste, as in the urine, and *secretion* when they are of some further use to the body, as in the gastric juice. Finally, it is possible that an expenditure of energy is involved in the conveyance of the impulse which starts any response from the spot where the stimulus is received to the locality where the main part of the response takes place. Thus, when a drop of water which has fallen upon the skin is brushed off, an impulse is started in the skin and conveyed along those tracts of the body which we know as nerves till it causes such movements of the muscles of the arms as are necessary to brush off the drop. This property in living matter of conveying impulses is known as *conductivity*. The mode of conduction is not understood, but it may be that it involves the evolution of energy by the disintegration of the conducting substance.

It should be noted that the forms in which the energy of the body is used in these various processes are very different. Besides mechanical movement, the exhibition of *molar* energy, it may bring about *chemical* changes, or become *heat* as is shown by its warming the human body, or *light*, as in the glow-worm, or *electricity*, as in the well-known electric eel, and less conspicuously in many events in the human and

other living bodies ; and there are other processes, such as secretion, its action in which has not yet been certainly compared with any event in the lifeless world and is sometimes supposed to be of a kind peculiar to the living body.

Incorporation of Food: (a) Absorption.

It is thus characteristic of the living body to be continually wasting away by disintegration. Clearly this could not go on indefinitely without some compensating repair. The waste is made good by the *incorporation* of food. Two distinct processes may be recognised in incorporation—absorption and assimilation. (*a*) Before it can be absorbed the food has generally to undergo a preliminary process of *digestion*, whereby the solid or indiffusible nutriment which it contains is made soluble and diffusible. The food of all animals must contain the following materials : (1) *water*, (2) certain *inorganic salts*, such as the chlorides and phosphates of sodium, potassium, and calcium, (3) the very complex compounds known as *proteins*. A protein is a colloid substance consisting of carbon, hydrogen, nitrogen, and oxygen, with small quantities of sulphur and sometimes phosphorus. A familiar example is the " albumin " which, mixed with water, forms white of egg. The molecular structure of proteins is not yet fully understood,[1] and they have not yet been made in the laboratory. Besides these substances the food usually contains (4) *carbohydrates* (sugars, starches, and related substances), (5) *fats*. Proteins, carbohydrates, and fats are among the compounds known as " organic," which, in nature, are found only in the bodies of plants and animals and in their remains ; all animals therefore require for food such bodies. From these some if not all animals must also obtain (6) traces of the mysterious *vitamins*. The digested materials undergo *absorption* into the substance of the body, leaving the indigestible matter to be cast away as the *dung* or *fæces*.

(b) Assimilation.

(*b*) Incorporation, however, is not brought about simply by the absorption of digested matter. The food, after as before digestion, is not of the same composition as the substance to which it is to be added. The flesh of a dead ox or sheep differs

[1] They are probably exceedingly complex linkages of amino-acids.

considerably in composition from that of a living man, and the difference is increased by its digestion. In the course of incorporation the food has therefore to undergo chemical changes by which it is converted into the substances which compose the body, and these changes it undergoes by the activity of the living matter itself. That is to say, the living substance has the power of making, out of unlike materials, additional matter of its own composition. The process by which this is done is known as *assimilation*.

(c) Results of Incorporation (1) Repair.

Both absorption and assimilation are processes in which work is done, and therefore involve the use of energy, but their net result is to add to the number of complex molecules, and therefore to the amount of energy, in the body. Part, at least, of the new complex material is used in the *repair* of the waste caused by disintegration

Metabolism.

It will be seen that disintegration and its complementary assimilation constitute a series of chemical changes, continually taking place in the body, whereby there is kept up a continual evolution of energy. These changes, regarded as a whole, are known as *metabolism*, the disintegrative changes being known as *katabolism* and the assimilative as *anabolism*.

(2) Growth.

The incorporation of new material has, however, a further effect than the mere repair of waste. Throughout the body of a young animal, and in such parts as the roots of the hair and nails even in age, incorporation takes place in excess of waste, so that *growth* occurs. Both in repair and in growth the new material is not added in layers to a surface, like that which is taken up by a crystal, but is placed between the existing particles, as a substance is taken into solution. Growth, moreover, is a very complex architectural process in which the intricate structure of the body is built up out of many materials.

Reproduction.

Growth is followed, sooner or later, by *reproduction*. That is to say, a portion of the body breaks off to form a new individual which leads an independent existence. It will be convenient to use the word "fission" to denote the actual breaking away of the new body, for reproduction is more than a

nere act of separation. This will be seen if we consider t a little more closely.

(*a*) As has been said, *reproduction always involves the* *ssion of an existing body.* Life never arises anew, but is lways passed on from one living being to another which rises from it. A living being which divides to produce thers is a *parent*; those which it forms are *offspring*.

(*b*) *The offspring are always at first unlike the parent.* There are, as we shall see, certain animals in which the only evident difference between the offspring and the individual by whose division they arose is the necessary one of size. But in the great majority of cases there is also an obvious difference in form, the offspring being at first very unlike the parent in structure. This difference is obscured in the case of man and some other animals, where he offspring undergoes changes in the womb before birth Fig. 1), but it is seen unmistakably in animals which are born in the condition of an egg. In their immature condition the offspring are known as *reproductive bodies*.

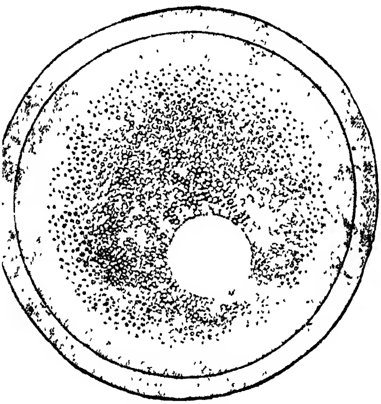

FIG. 1.—The egg or "ovum" from which a human being is developed, highly magnified.

(*c*) In spite of this unlikeness at starting, *the offspring become in time like the parent from which they arose*, owing o a succession of changes which is sometimes straightforward, or *direct*; sometimes, as in the well-known case of he butterfly, very roundabout, or *indirect*. Thus the life of an animal is a *cycle*, in which it passes through a series of stages, beginning with the small and simple reproductive body, and ending with the larger and usually more complex *adult*, ready to undergo fission again. Every individual

goes through the same cycle of changes as its parent, resembling in each stage a similar stage passed through by the latter, till it reaches the likeness of the individual that produced it. This is due to the property known as *heredity*. Thus, in the strict sense of the word, reproduction includes the whole life cycle, and consists of two distinct processes—*fission* and the *development* of the reproductive body into the adult—for until this cycle has been completed the parent is not re-produced.[1] From this point of view, *growth* is that part of the process of development by which the reproductive body reaches the size of the adult. At the same time, in most cases, and perhaps in all, the growing individual is undergoing the *changes in structure* to which we have alluded.

Conjugation. Here must be mentioned a process which, though in itself it is not reproductive, is closely connected with reproduction. It is well known that in most animals reproduction is only possible by the co-operation of two individuals of different kinds known as the *sexes*. This is because in such animals the reproductive bodies are of two sorts, each produced only by one of the sexes, and neither sort can develop except after fusion with one of the other sort. That fusion is an example of the process known as *conjugation*. From time to time there occurs in nearly all animals such a union of two distinct portions of living matter. The bodies which unite are known as *gametes* and that which results from their fusion as a *zygote*. In large and complex animals conjugation takes place only between the reproductive bodies, which are generally unable to develop without it, so that, as we have seen, it becomes a part of the reproductive process. In these cases the reproductive bodies are of a kind known as *germs*, distinguished from other repro-

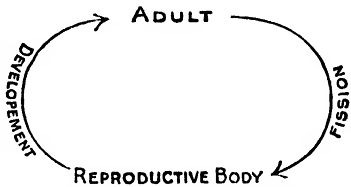

FIG. 2.—A diagram of the life-cycle of an animal.

[1] Development may partly take place before fission, as in many cases of budding (Chap. IX.).

mere act of separation. This will be seen if we consider it a little more closely.

(*a*) As has been said, *reproduction always involves the fission of an existing body*. Life never arises anew, but is always passed on from one living being to another which arises from it. A living being which divides to produce others is a *parent*; those which it forms are *offspring*.

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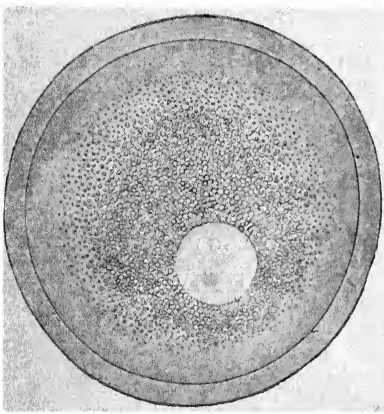


FIG. 1.—The egg or "ovum" from which a human being is developed, highly magnified.

(*c*) In spite of this unlikeness at starting, *the offspring become in time like the parent from which they arose*, owing to a succession of changes which is sometimes straightforward, or *direct*; sometimes, as in the well-known case of the butterfly, very roundabout, or *indirect*. Thus the life of an animal is a *cycle*, in which it passes through a series of stages, beginning with the small and simple reproductive body, and ending with the larger and usually more complex *adult*, ready to undergo fission again. Every individual

ductive bodies by their small size and the simplicity of their structure. The germs of such animals are, as has been said, of two sorts. One is larger and passive, and is known as the *egg*, *ovum*, or *female gamete*. The other is smaller and active, and known as the *spermatozoon* or *male gamete*; it moves to the egg and enters it, and is then said to *fertilise* it. Ova and spermatozoa are usually formed by different adults, known respectively as *female* and *male*, but in some cases both kinds are formed by one individual, which is then known as a *hermaphrodite*. In some aquatic animals the gametes are set free, and conjugation takes place outside the body of the parent. In many cases, however, the ova are kept within the body of the mother, and the male gametes, known collectively as the *sperm*, are transferred by the male to the body of the female and there seek and fertilise the ova. This transference is known as *coition*. Reproduction in which conjugation is necessary before the reproductive bodies can develop is known as *sexual reproduction*. In some of the smallest animals, conjugation takes place, not between newly-formed germs, but between fully grown adults, and thus has not its usual connection with reproduction.

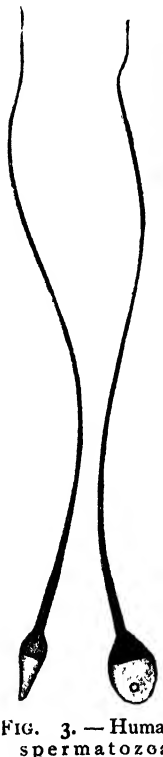


FIG. 3. — Human spermatozoa, highly magnified, seen in face and in side view.—After various authors.

Irritability.

The complex process, life, that has now been described, is directed, and caused to have the results that it has for the being in which it takes place, in two ways, due respectively to two properties of the living being which are known as *Irritability* and *Automatism*. Irritability is the property of acting in response to external events. Thus, in various animals, the coming into sight of an enemy will cause action in the form

of flight or preparation for defence; the smell of food sets the mouth watering; rise in temperature brings about breeding; and so forth. The events external to itself to which the living being responds by action are known as *stimuli*. Two things must be noted concerning the activity started by them. Firstly, that its energy is derived, as we have seen, not from without, as when a change is brought about in water by heating it, but from within, as when a change is brought about in gunpowder by heating it. Secondly, that the extent of the internal change bears no relation to that of the external one which acts as its stimulus. Thus when, in response to a command, a man lifts a heavy load, the energy of the sound-waves which call forth this reaction is immeasurably smaller than that of the work done by the man, and either may be greater or less without a corresponding alteration in the other.

Automatism.

Activity, however, is not necessarily associated with irritability. It is sometimes claimed that the activity of living animals is characterised by a feature which is in its essence the very opposite of irritability. This feature is called *automatism*. Automatism is the occurrence in the body of activity which is not the direct result of any stimulus from without. The simplest instance of this is the beating of the heart, but we are well aware that some of our more complicated actions are at least not due to any stimuli which we can trace. In view of the great number of stimuli which the body is always receiving, it is necessary to be cautious in attributing an automatic character to any of its actions, but there is little doubt that automatism, in the sense in which we have used the word, is characteristic of the living being.

Summary of the Characteristics of Life.

We are now in a position to sum up the characteristic features of the complex process which is known as life. In doing so we shall arrange them in a somewhat different order from that in which they have come under our notice, stating successively those that relate to the starting and stopping of the life processes, to the nature of these processes, and

to the end to which they tend. We have found in life the following features :[1]—

1. *Irritability*—the starting or stopping in the body of an activity of its own as the result of the receipt of a stimulus.
2. *Automatism*—the starting or stopping of activity without an immediate external stimulus.
3. *Disintegration with liberation of energy*, this energy appearing in various processes, of which the most conspicuous are :
   - i. *Contraction*, or change of shape,
   - ii. *Chemical work*,
   - iii. *Excretion and Secretion*, the shedding out from the substance of the body of chemical products,

   and possibly also in the *Conduction* of the impulses which start these processes from one part of the body to another.
4. *The Incorporation of food*, which involves (*a*) the *Absorption* of new material, (*b*) the conversion by *Assimilation* of unlike substances into the substance of the body.
5. *Purposiveness*—the direction of the activities of the body towards an end which concerns itself, namely to its own preservation and that of its kind. This is shown :
   - i. as regards the individual, in the *Struggle for Existence*—the obtaining of food, and the avoidance or overcoming of enemies and unfavourable circumstances ;
   - ii. as regards the race, in *Reproduction*—the bringing into existence of new individuals, which involves (*a*) the breaking off by *Fission* of a part of the body, and (*b*) the process of growth and structural and chemical change known as the *Development* of the part broken off.

[1] The process of respiration is not included in the following list because, though it is often rightly cited as a characteristic feature of the life of animals, it is not a simple or distinct process. It consists in the excretion of carbon dioxide and the taking up of oxygen by a process

Structure and Function: Organisation. The relation of the life of animals and plants to their structure is very clear in the light of what has just been said. The living body is a machine which reacts to events in the outer world in such a way as to prolong its own existence and that of its kind. Like other machines, it consists of a number of parts each of which does a particular portion of the work of the whole. Such parts are called *organs*. Thus there are *sense organs*, such as the eyes and ears, for the reception of stimuli; *nervous organs* for the conduction of impulses set up by these and other stimuli, to the organs which carry out the main part of the reaction; *locomotive organs*, such as legs and wings and fins, to carry the body towards food or from danger; *organs of offence and defence*, such as teeth and claws, for procuring food and resisting attack; *organs of digestion*, such as the stomach and bowels; *organs of circulation*, such as the heart and blood vessels, to convey the digested food about the body and to carry waste matters to the *excretory organs*, such as the kidneys; *organs of respiration*, such as lungs and gills; *organs of reproduction*, and so forth. An organ may consist of subsidiary organs. Thus the leg is supported by *skeletal organs* known as bones, moved by *muscles*, and served by *blood vessels* and *nerves*. A complex of parts which work together is known as an *organism*, and this name is often applied to animals and to plants, for plants are also provided with organs, and also alive. The provision of separate organs for particular functions is called *organisation* or *differentiation*; the assignment of particular functions to separate organs which corresponds to organisation is called, by analogy with the similar separation of functions in modern industry, *the physiological division of labour*. Organisation exists to a very various extent among organisms, and of two organisms that which has the larger number of different organs is said to be the *more highly organised* or *more highly differentiated*, or simply the *higher*. Thus man is a higher organism than a jellyfish. There are also great differences in form between the

which is not in its essence different from the incorporation of other materials. Conjugation is rejected because it is not a universal property of living matter.

organs of animals of the same grade of organisation. Thus a butterfly is as highly organised as a fish, but its organs are utterly different in form. The differences in structure between animals correspond to differences in their modes of life. An animal which lives in water has, for instance, very different organs of locomotion and respiration from one which lives on land; the sense organs of an internal parasite are much less highly differentiated than those of an animal which has to seek food and avoid

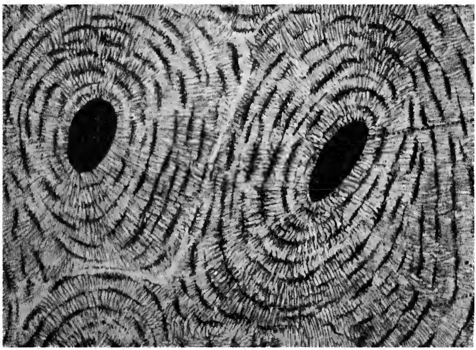


FIG. 4.—A section of dry bone magnified. The dark spaces show where the living part of the tissue was lodged.

lac., Spaces known as "lacunæ." In these lay the cells into which the protoplasm was divided. *g.s.*, ground substance. This is traversed by numerous "canaliculi" in which processes of protoplasm united the cells into a meshwork. *H.c.*, "Haversian canals" in which minute blood vessels lay. The lacunæ are so arranged as to divide the ground-substance into concentric layers or "lamellæ" around the Haversian canals.

enemies from hour to hour; and a carnivorous animal has organs for seizing and eating its food which are different from those of one whose diet is vegetarian. This correspondence between organisation and mode of life is known as *adaptation*.

Tissues.

Organisation involves more than the mere existence of organs—more, that is, than the shaping of the body into regions where special functions are performed It involves also a specialisation of each of

these regions to fit it for its special functions. This specialisation is found partly in the shape of each organ, but also largely in its texture and composition. The substance of the body is not alike throughout, but different portions of it have differences in texture and chemical composition which confer upon them different properties. Thus the outer layer of the skin is firm and hard to penetrate, bone is rigid, blood is fluid, the substance known as "connective tissue" is tough and binds other tissues together,[1] nerve has the power of conduction highly developed, and muscle that of contraction, and so forth. Such a portion of the body-substance with particular properties, due to a particular texture and composition, is known as a *tissue*. An organ may consist of one tissue throughout, but is usually built up of several, upon the nature and arrangement of which its powers depend. Thus a muscle contains, besides muscular tissue, connective tissue to bind it together and nervous tissue to conduct through it the impulses which cause it to contract.

Protoplasm.

We have hitherto spoken of the body as though it were alive throughout. That, however, is rarely the case. The living part of the body of all animals is a soft, slimy substance known as *protoplasm*. In a few cases this forms the whole body, but in most it is only a part. All tissues contain protoplasm, but many contain also a framework of other substances known as *formed material*, made and secreted by the protoplasm and serving for its support. Thus in bone (Fig. 4) there is a groundwork, consisting largely of salts of lime, to which it owes its hardness, and this groundwork is penetrated by a meshwork of protoplasm. In composition, protoplasm is a solution in water of organic substances and salts, especially characterised by the presence of proteins. In many cases, as we shall see in a later chapter, the protoplasm is divided into minute units known as *cells* (Fig. 5).[2]

We have now to observe what are the differences between animals and the members of the other principal division

[1] This may be seen in skinning any large animal. The tough, white material which holds down the skin and binds the muscles together is connective tissue.

[2] For the definition of this term see p. 85.

of living beings, the plants. There is no fundamental difference in the composition of the protoplasm which is the essential part of all living things. Nor do they differ in the essentials of their life. This may be seen by comparing the activities of plants with those which we have studied in animals. That the protoplasm of plants is irritable we see in such cases as the turning of a sunflower

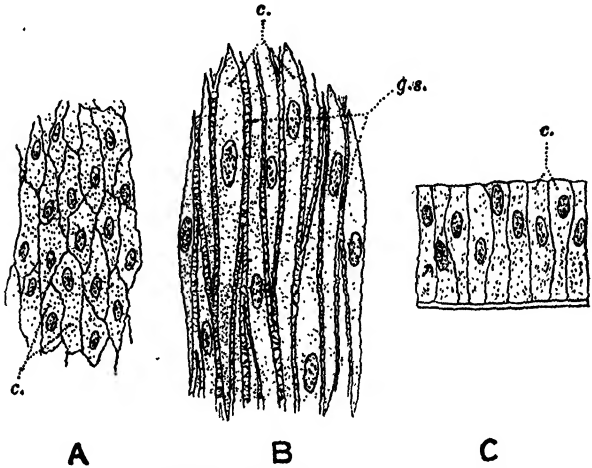


FIG. 5.—Portions of tissues, highly magnified, to show cells.

A, The lining of an artery; *B*, muscular tissue from the wall of the intestine; *C*, the lining of the intestine. *A* and *B* are shown in surface view, *C* in section.
c., Cells; *g.s.*, *ground* or intercellular substance, traversed by threads of protoplasm from cell to cell.

towards the sun, or the stimulation by gravity of the stem to grow upward and the root downward, or the folding of the leaves of the Sensitive Plant (*Mimosa*) when they are touched. That it is automatic appears in such facts as the slow turning of the tendrils of climbing plants till they meet with objects to which they can cling. That it has conductivity can be seen when a stimulus given to the leaf of a mimosa causes distant leaflets to fold. That it can execute movements may in many cases be seen under the

microscope, when it will be found to stream round the cell. That it makes substances by chemical activity and secretes them is illustrated by the long list of drugs and other substances obtained from plants. That it grows and reproduces need not be argued.

Differences between Animals and Plants.

For all this agreement in essentials, however, there are between animals and plants distinctions which are both far-reaching and obvious. We may take our start from familiar notions on the subject. Any one who tried to state in words the ideas which he had unconsciously formed of animals and plants would probably find them to be somewhat as follows: An animal is a being that moves and feeds; a plant is a green thing that grows in the earth. Let us examine these notions. It will be best to base our analysis upon our definition of a plant. We find that the information it implicitly contains is: (1) That the plant is green, (2) that it does not swallow food, but draws nourishment from the earth (the fact that it also obtains food from the air is less generally known), (3) that it is fixed in one place and does not move about—usually, indeed, does not move at all.

1. The green colour of plants is due to the presence of the substance known as *chlorophyll* (p. 156). This is never found in animals, except in certain cases where minute green plants live embedded in the protoplasm of animal bodies, as in the green *Hydra*. At the same time it must be remembered that certain plants, such as the fungi, have no chlorophyll.

2. More important than the mere presence of chlorophyll is its function in the body, which is connected with the *nutrition* of the plant. We shall see (p. 156) that this function is the obtaining of carbon from carbon dioxide by means of the energy of the sun's rays, the carbon being caused to combine with the elements of water to form carbohydrates, and afterwards with nitrogen, sulphur, and phosphorus obtained in inorganic salts, to form more complex organic substances. From this peculiarity of nutrition arise several other features peculiar to the life of plants. (i) We have here the reason for the well-known fact that green plants cannot live in the dark. (ii) While

animals, as we have seen, are always taking in oxygen and giving out carbon dioxide, green plants in the light are continually taking in carbon dioxide and giving out oxygen. Yet it must be remembered that the protoplasm of plants undergoes continually a true respiration like that of animals although this is obscured by the reverse process taking place to a greater extent during daylight. (iii) While the food of animals consists of complex organic substances, usually in the state of a solid or the viscous liquid protoplasm, and has to be swallowed through an opening, the materials taken in by green plants are simple inorganic substances which can be absorbed as gases or liquids through the surface of the body. It must be noticed, however, that plants which have no chlorophyll, such as fungi, and some animals which live as parasites or in decaying matter, absorb their nourishment through the surface of the body, but take it in the form of organic substances, more or less complex in various cases, from the living or dead bodies of other organisms.

3. From the mode of nutrition of plants there follows the third character which we have marked in them. In the great majority of animals food must be either sought by locomotion or at least seized by other *active movements*, as it is, for instance, in a sea-anemone or Hydra (p. 149). In plants, on the other hand, not only is this necessity absent, but, since it is desirable that they should expose as great a surface as possible to air and water for absorption—as they do, for example, in leaves and roots—the shape of their bodies is necessarily such as to be an actual hindrance to motion. Thus, in most plants active motion is restricted or absent, and muscular and nervous tissues are not found in plant bodies.

4. The necessity for surface leads to a fourth character in plants. An extensive surface needs strong support. In correspondence with this need we find in plants a massive skeleton which forms a strong wall to each cell, so that the protoplasm is upheld by an intricate framework of compartments whose walls are thickest in the most woody parts of the body. Owing, no doubt, to the ample supply of starch at the command of the plant, this skeleton consists of a modified form of starch known as *cellulose*. Among

plants, even including those like the fungi which have no chlorophyll, cellulose is almost invariably present; among animals it is unknown. It happens, indeed, that this comparatively unimportant character comes nearer than any other to giving an absolute distinction between the two kinds of organisms.

To sum up: we find between typical plants and typical animals the following distinctions:—

1. The presence in typical plants and not in animals of the green substance *chlorophyll.*

2. That while plants absorb through their surface simple inorganic compounds and from them *manufacture foodstuffs* for their protoplasm, animals swallow the complex substances of the bodies of plants and of other animals.

3. That while in plants *motion is restricted* or absent, it is conspicuous in animals.

4. That plants have a skeleton of *cellulose,* which is absent from the bodies of animals.

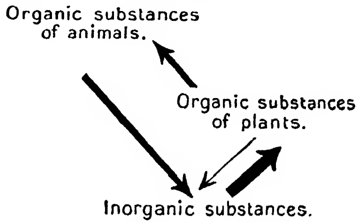


FIG. 6.—A diagram of the circulation of matter through the bodies of organisms.

The Balance of Nature.

The fundamental difference in nutrition between animals and plants has an important result in regard to their relation with the rest of nature and with one another. In their action upon the inorganic world these two kinds of organisms bring about precisely opposite changes, and do so in such a way that each sets up conditions favourable to the activity of the other. The plants, absorbing the energy of the sun's rays, build up with storage of that energy complex organic compounds from simple inorganic substances.[1] These manufactured substances it assimilates, partly in repairing the waste of its protoplasm, but mainly in adding to its substance by growth. Its construction of organic materials

[1] The storage of energy is of course due to the fact that more is absorbed in splitting the stable inorganic molecules than is freed in forming the unstable organic molecules.

is in excess of its destruction of them, and the net result of its activity is to provide an accumulation of those complex substances which form a necessary part of the food of protoplasm. At the same time it sets free oxygen. The animal, on the other hand, obtains the organic food for its protoplasm by consuming the substances manufactured by plants, either directly from the plant body or after they have been incorporated in a somewhat altered form into the protoplasm of other animals. In the protoplasm of the animal these substances undergo destruction. Thus the animal destroys organic material without, like the plant, manufacturing from inorganic matter more to replace it. The

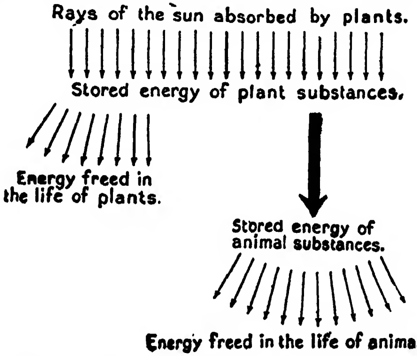


FIG. 7.—A diagram of the energy of organisms.

net result of its life is to lessen the amount of organic matter in the world. At the same time it sets free carbon dioxide and simple nitrogen compounds. Thus plants provide food and oxygen for animals, while animals, destroying this food, provide simple nitrogen compounds [1] and carbon dioxide for the use of plants. The result is a *circulation of nitrogen and of carbon* through the bodies of organisms. It will be seen that this circulation of matter is accompanied by a transference of energy. The whole of the energy of the life both of plants and of animals is derived in the long-run from the energy of the sun's rays

[1] These are usually not available for the use of plants till they have been turned into nitrates by the action of bacteria.

stored by plants in the complex substances they manufacture. It is stored by plants : most of it is not set free till it reaches the bodies of animals. There is, of course, no circulation of energy. That which is set free from the bodies of organisms is lost to them, and has to be replaced by the fixing of more energy from the sun's rays by plants when they work up the excreta of animals.

Anatomy and Physiology.

Biology is divided into *Botany*, which deals with plants, and *Zoology*, which deals with animals. Now an organism may be regarded from two points of view according as attention is concentrated upon its structure or its functions, though of course the connection of structure with function makes it impossible to study either without reference to the other. The sciences of Zoology and Botany are correspondingly divided each into two subordinate sciences, *Anatomy* or *Morphology*, which deals with the structure of the bodies of organisms, and *Physiology*, which deals with their functions. In the following pages we shall regard Zoology in the first place from the anatomical point of view, but shall seek from Physiology light upon the meaning of the structures described, endeavouring to trace in the bodies of the animals studied the provision which exists for carrying out all those functions which our first survey has revealed to us as taking place. With this purpose we shall examine in considerable detail first one of the higher animals and then an exceedingly simple example, tracing afterwards, in a series of further examples, the gradual increase in organisation and the varieties that it presents. Finally we shall discuss certain topics which concern animals in general.

CHAPTER II

THE FROG: EXTERNAL FEATURES AND BODY-WALL

Habits.

THE Common Frog of Britain is the species known in Zoology as *Rana temporaria*. It is abundant in summer in damp places, but in winter is less easily found, owing to the fact that it is then in a torpid

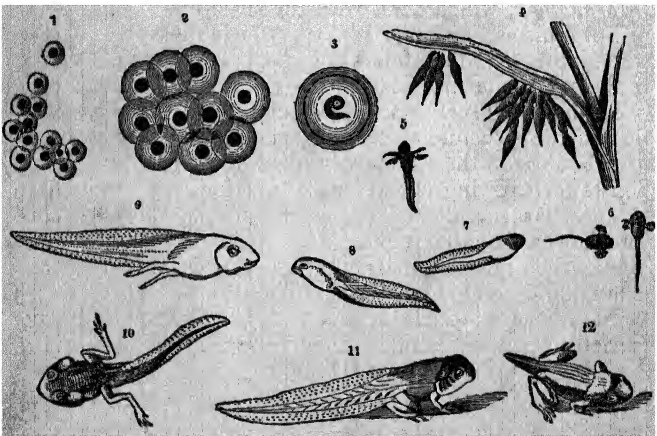


FIG. 8.—The life-history of a frog.—After Brehm.

1–3, Developing ova; 4, newly hatched forms hanging to water-weeds; 5, 6, stages with external gills; 7–10, tadpoles during emergence of limbs; 11, tadpoles with both pairs of limbs apparent; 12, metamorphosis to frog.

state, hidden in holes or buried in mud. In the spring the warmth wakes the frogs and they congregate, croaking loudly, and pair in the water, where the eggs are laid as a

mass of spawn and fertilised by the sperm which the male sheds over them as they pass out of the female. In about a fortnight there hatches from each egg a little, fish-like *tadpole*. This has no limbs, but a strong tail, which it uses for swimming, breathes wholly by gills, and is at first without a mouth. In a few days a mouth appears and the animal begins to feed on vegetable matter. Gradually it changes, losing its gills and tail and gaining lungs and two

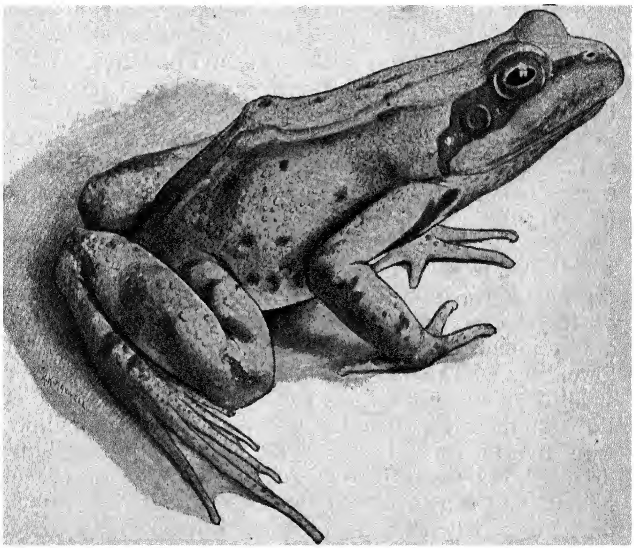


FIG. 9.—The Common Frog.

pairs of limbs, till at the end of three months it becomes a small frog. Henceforward it lives principally on land, sometimes crawling about by means of both pairs of limbs, but generally jumping with the strong hinder pair and using the small fore pair to break its fall when it alights. When it is frightened, however, it occasionally takes to the water, and then swims strongly with its hind limbs. Its food, after it has left the water, consists of slugs, snails, insects, worms, and other small animals, the smaller prey being caught by a sticky tongue, the larger seized with the mouth.

External Features.

In examining the body of a frog, we are struck, first by the fact that its mottled green and yellow skin is soft and slimy and without the covering of hairs, or scales, or feathers which we find in other animals, and next by its consisting only of head, trunk, and two pairs of limbs. There is no neck or tail. The *trunk* is flattened and bears the head at one end and the limbs of each pair opposite to one another on the narrow sides. In consequence of this symmetrical arrangement we may distinguish a *back or dorsal surface*, a *lower or ventral surface*, right and left sides, and fore and hind ends. Such a symmetry is called *bilateral*, and we shall see that in the frog it extends to the arrangement of nearly all the organs of the body. The *fore or anterior end* is that which is foremost when the animal moves, and is thus the first part to come into relation with objects in the world around it. At this end is placed the *head*, a distinct region of the body, smaller than the trunk, which bears the mouth with which food is taken and the three pairs of principal sense organs by which the animal becomes aware of the nature of its surroundings. The *eyes* are large, and have stout, almost immovable upper lids and thin, translucent, movable lower lids.[1] The *nostrils or external nares* are a pair of small openings on the top of the head in front of the eyes. Each of them leads into a chamber which communicates with the mouth. There is no flap to the *ear*, but the drum shows upon the surface at the side of the head behind and somewhat below the eye. If the drum be pierced, a bristle passed through it will be found to reach the mouth. On the lower side of the trunk there may be distinguished two regions—the large, soft-walled *belly or abdomen* behind, and the smaller stout-walled *breast region* in front.

The *limbs* of each pair resemble one another, and those of the two pairs correspond roughly in shape, each consisting of three successive parts, the first two slender and the third broad and adapted to be applied to the ground. In the *fore limb or arm* the segment nearest the body is

[1] These do not represent the lower lids of man, which are wanting in the frog. The lower lid of the frog is the *third eyelid or nictitating membrane* found in many other animals (p. 259). All three eyelids are well developed in birds.

known as the *upper arm or brachium*, the middle segment as the *forearm or antebrachium*, and the third segment as the *hand or manus*. In the hand may be distinguished a *wrist or carpus*, a *palm or metacarpus*, and *fingers or digits*, of which there are only four, that which corresponds to the thumb or pollex of man being absent. The first finger of the male frog bears at the breeding season a rough-skinned swelling, not unlike the ball of the human thumb. In the *hinder limb or leg*, which is longer than the arm, the first segment is known as the *thigh or femur*, the second as the *shank or crus*, the third as the *foot or pes*. The foot contains regions corresponding to those of the

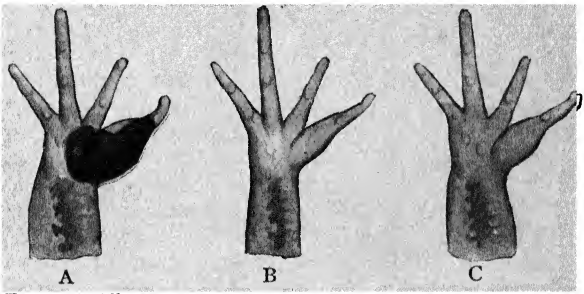


FIG. 10.—The palm of the right hand, *A* of a male frog at the breeding season, *B* of a female, *C* of a male out of the breeding season.

hand, and known respectively as the *ankle or tarsus*, *instep or metatarsus*, and *toes or digits*, but the ankle is much longer than the wrist, and all five toes are present and united by webs of skin, so that a wide surface is provided for use in swimming. The lower side of the foot is called the *plantar surface*, that of the hand the *palmar surface*.

Between the legs at the *hinder or posterior end* of the trunk is the *cloacal opening*, through which are passed the fæces, urine, and eggs or sperm.

Skin. The skin of the frog is a thin, tough, protective covering. It contains glands of several kinds, and pigment cells (Fig. 55). Between them the glands provide a slimy liquid, which possesses to a slight extent the acrid property found in the secretion of the skin

of toads and newts. The pigment in the cells expands and contracts in varying conditions of light and temperature and thus alters the colour of the frog. Cold, dark, or wet surroundings cause expansion of the pigment and darkening of the skin. Warmth, light, or dryness cause contraction (Pl. II.). From time to time the horny outer layer of the skin is shed and eaten by the frog.

General Arrangement of Internal Organs.

Immediately below the skin is a series of large spaces, the *subcutaneous lymph sacs*, containing a fluid known as lymph (p. 60). Between the lymph sacs the skin is bound down to the underlying flesh by tough, white connective tissue, but in consequence of the presence of the sacs it is much looser than that of most animals. Below the sacs the body possesses a continuous layer of flesh, which consists, as the substance so-called always does, of muscles. There is thus a *body-wall*, composed of skin and muscles, with bones and a lining of peritoneum (to be mentioned shortly), and this wall encloses in the trunk a large space, the *body cavity or cœlom*, in which lie most of the principal *viscera*. The latter name is applied to the soft internal organs of the body, such as the stomach, bowels, liver, lungs, and heart. The body-wall of the back is much thicker than that of the belly, and in it is embedded a structure known as the *backbone, spine, or vertebral column*. This consists of a row of ring-like bones, the *vertebræ*, placed end to end to form a tube, the *vertebral or spinal canal*, in which lies a part of the nervous

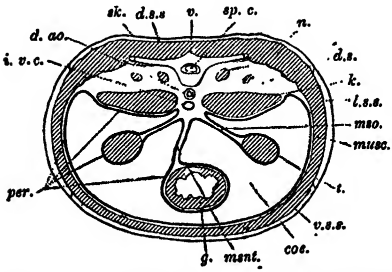


FIG. 11.—A diagram of a transverse section through the abdomen of a male frog.

coe., Cœlom; *d.ao.*, dorsal aorta; *d.s.*, dorsal lymph sac; *d.s.s.*, dorsal subcutaneous lymph sac; *g.*, gut; *i.v.c.*, inferior vena cava; *k.*, kidney; *l.s.s.*, lateral subcutaneous lymph sac; *msnt.*, mesentery; *mso.*, mesorchium; *musc.*, muscular body-wall; *n.*, spinal nerves; *per*, peritoneum; *sk.*, skin; *sp.c.*, spinal cord; *t.*, testis; *v.*, vertebra; *v.s.s.*, ventral subcutaneous lymph sac.

system known as the *spinal marrow or cord.* The muscles of the ventral side are thicker at the ends of the trunk, where they contain bony hoops, the *shoulder girdle and hip girdle,* which, with the vertebræ between the upper ends of each of them, encircle the body. The cœlom is lined by a smooth membrane, the *peritoneum,* which is continued over the viscera, so that these are not truly exposed in the body cavity, but hang into it in folds of the peritoneum (Fig. 11). Each fold fits closely over the organ which it suspends, and above the organ the two sides of the fold come together to form a sheet which slings the organ from the body-wall. The largest of these suspensory sheets is that which holds the gut and is known as the *mesentery.* Between the peritoneum and the muscles of the back is on each side a large *dorsal lymph sac,* and in each dorsal lymph sac lies one of the pair of kidneys. In the head there is no body cavity, and the backbone is here continued by a large box of bone and cartilage known as the *skull,* while the spinal cord is prolonged into the skull by the *brain.* The limbs have neither body cavity nor viscera, and among their muscles lie the bones which support them.

Skeleton: General Arrangement.

The skeleton of the frog is composed chiefly of *bone,* but contains also a good deal of a gristly substance known as *cartilage.* There may be recognised in it an *axial part,* consisting of the skull, backbone, and breastbone, which supports the trunk and head, and an *appendicular part,* comprising the bones of the limbs and their girdles, which supports the arms and legs and anchors them to the trunk.

Backbone.

In the backbone there are nine vertebræ and a long bone, known as the *urostyle,* which represents several vertebræ fused together. The ninth is known as the *sacral vertebra,* and to it is attached the girdle of the hind limbs. Each vertebra consists of a *body or centrum* and an arch, the *neural arch,* placed above the centrum so as to form a ring around the spinal cord. The hollow of each ring is a *vertebral foramen,* and the rings together form the vertebral canal. The roof of each arch is raised into a low ridge, the *neural spine or spinous process,* and in every vertebra except the first the arch bears on each side, a little above its junction with the centrum, a

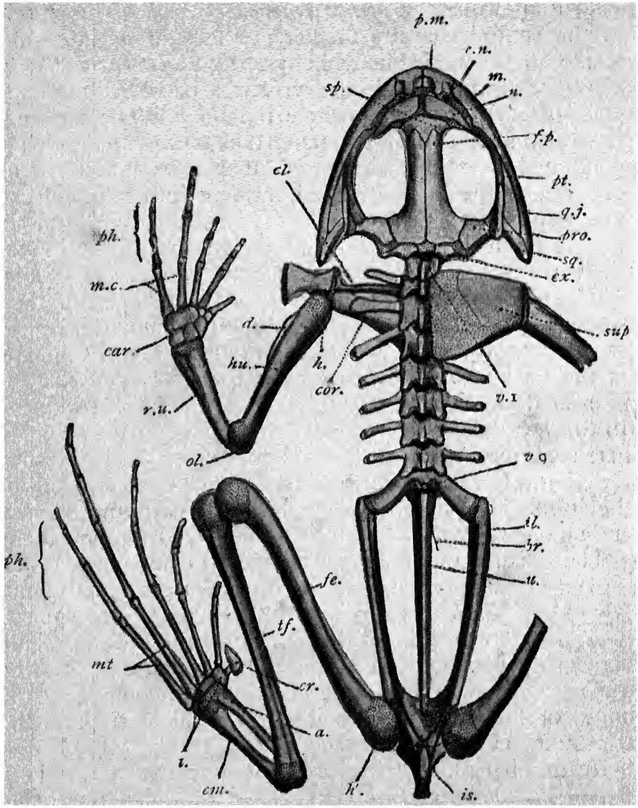


FIG. 12.—The skeleton of a frog, seen from above.

a., Astragalus; *br.*, bristle passed into opening for last spinal nerve; *car.*, carpal or wrist bones; *cl.*, clavicle; *cm.*, calcaneum; *cor.*, coracoid; *cr.*, calcar; *d.*, deltoid ridge; *e.n.*, external narial opening; *ex.*, ex-occipital; *fe.*, femur; *f.p.*, fronto-parietal; *h.*, *h'.*, heads of humerus and femur; *hu.*, humerus; *il.*, ilium; *is.*, ischium; *m.*, maxilla; *m.c.*, metacarpals; *mt.*, metatarsals; *n.*, nasal bone; *ol.*, olecranon process; *ph.*, phalanges; *p.m.*, premaxilla; *pro.*, prootic; *pt.*, pterygoid; *q.j.*, quadratojugal; *r.u.*, radioulna; *sp.*, sphenethmoid; *s.q.*, squamosal; *sup.*, suprascapula; *t.*, distal tarsals; *tf.*, tibiofibula; *u.*, urostyle; *v.*1, first or atlas vertebra; *v.*9, ninth or sacral vertebra.

The dotted regions consist of cartilage. The cartilage at the ends of the limb bones is the "articular" cartilage which caps the enlarged ends of the bones.

transverse process, which is especially large in the sacral vertebra. At the end of each transverse process is a small knob of cartilage which represents a *rib*. That part of the arch which lies between the transverse process of each side and the neural spine is known as a *lamina*, and the part between the centrum and the transverse process is a *radix or pedicle*. Each vertebra is jointed to those in front and behind it by projections, one on each side at each end of the arch, at the junction of transverse process and lamina, known as *zygapophyses*. The zygapophyses in front of the vertebra (*prezygapophyses or superior articular processes*) have each a flat surface facing upwards. Those behind (*postzygapophyses or inferior articular processes*) have flat surfaces facing downwards which fit on to the surfaces of the prezygapophyses and slide over them as the backbone bends. The front and hind edges of each pedicle are concave, forming thus *intervertebral notches*, and the adjoining notches of two vertebræ form an *intervertebral foramen*, through which a nerve passes from the spinal cord. Most of the centra are hollow in front and rounded behind and thus fit together by ball-and-socket joints, but the first vertebra has in front two hollows, which serve as sockets for two knobs, known as the occipital condyles, on the hinder end of the skull, while the eighth is hollow behind as well as in

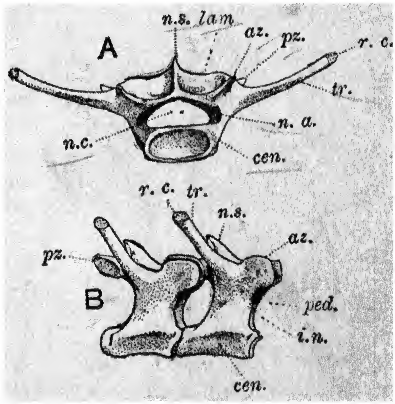


FIG. 13.—Vertebræ of a frog. *A*, fourth vertebra, seen from in front; *B*, sixth and seventh vertebræ from the right.

az., Prezygapophysis; *cen.*, centrum; *i.n.*, intervertebral notch; *lam.*, lamina of neural arch; *n.a.*, pedicle of same; *n.c.*, vertebral foramen; *n.s.*, neural spine; *ped.*, pedicle; *pz.*, postzygapophysis; *r.c.*, cartilage at end of transverse process; *tr.*, transverse process.

front, and the ninth projects in front, to articulate with the hollow of the eighth, and has behind two knobs which articulate with two hollows on the urostyle. The latter is a long, tapering bone with a ridge above, in the front part of which is a canal for the hinder part of the spinal cord.

Skull. In the skull, the following regions may be distinguished: (1) the *cranium or brain case*, (2) the *nasal capsules*, which enclose the organs of smell, (3) the *auditory capsules*, which enclose the inner part of the ear, (4) the *visceral arches*, an apparatus which lies below the cranium and is highly developed in a fish and in the tadpole, but in the adult frog is represented only by the jaws and by a structure in the floor of the mouth known as the *hyoid*.

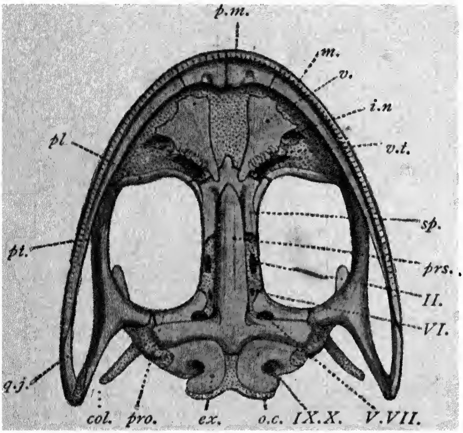


FIG. 14.—The skull of a frog, seen from below.

col., Columella; *ex.*, exoccipital; *i.n.*, internal narial opening; *m.*, maxilla; *o.c.*, occipital condyle; *pl.*, palatine; *p.m.*, premaxilla; *pro.*, prootic; *prs.*, parasphenoid; *pt.*, pterygoid; *q.j.*, quadratojugal; *sp.*, sphenethmoid; *v.*, vomer; *v.t.*, vomerine teeth; *II*, *V*, *VI*, *VII*, *IX*, *X*, foramina for cranial nerves.

The cranium is an oblong box, from which the nasal capsules project in front and the auditory capsules at the sides of the hinder end, while the bones of the upper jaw form a scaffolding fixed to the capsules and supporting the sides of the head. Between the scaffolding and the cranium is on each side a large space known as the *orbit* in which lies the eye. The hinder part of the cranium, between the auditory capsules, is known as the *occipital region*, the middle part, between the orbits, is known as

the *sphenoidal region,* and the front part, immediately behind the nasal capsules, is known as the *ethmoidal region.*

The skull consists of a foundation of cartilage taken over from the tadpole, with certain bones which are formed while the tadpole is changing into a frog. These bones may be divided into two sets according to the way in which they are formed. Those which arise by the replacement of parts of the original cartilaginous skull by bone are known as *cartilage bones.* Those which appear in development without being thus preformed in cartilage are known as *membrane bones* on account of the membrane, consisting of a sort of connective tissue, which at first occupies the places in which they will appear. The cartilage bones are embedded in the cartilage of the skull and cannot be removed, but the membrane bones can easily be taken off.

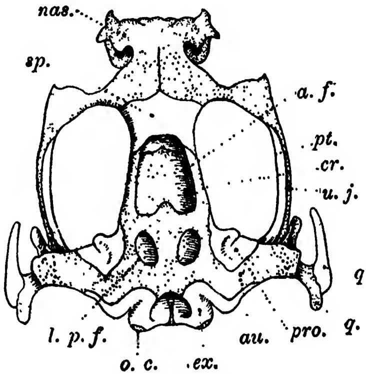


FIG. 15.—The cartilaginous skull of a frog, seen from above after the removal of most of the bones.

a.f., Anterior fontanelle; *au.*, auditory capsule; *cr.*, cranium; *ex.*, exoccipital; *l.p.f.*, left posterior fontanelle; *nas.*, nasal capsule; *o.c.*, occipital condyle; *pro.*, prootic; *pt.*, pterygoid; *q.*, quadrate; *q.j.*, quadratojugal; *sp.*, sphenethmoid; *u.j.*, upper jaw bar.

At the hind end of the cranium is a large opening known as the *foramen magnum,* through which the spinal cord is continuous with the brain. On each side of this is a cartilage bone called the *exoccipital,* which bears one of the *occipital condyles* mentioned above, but the foramen magnum is not completely bordered by the exoccipitals, since these are separated above and below by cartilage. The rest of the cranium is mainly composed of cartilage covered by certain membrane bones, but the front end is formed by a

cartilage bone known as the *sphenethmoid.* This has the form of a dice box divided across the narrowest part by a transverse partition which closes the cranial cavity in front. A longitudinal partition divides the front half of the box into two. The roof of the cartilaginous cranium is pierced by three large holes or *fontanelles*, but these are not seen in an intact skull, since the whole roof is covered, from the exoccipitals to the sphenethmoid, by two long bones, the *frontoparietals*, placed side by side. The floor is complete, and under it lies a large dagger-shaped bone, the *parasphenoid*, placed with the blade of the dagger forward and the crosspiece of its hilt under the auditory capsules.

The wall of the cranium is pierced by certain openings or *foramina*, for the passage of the nerves which arise from the brain. These "cranial" nerves are ten in number on each side. The *first nerve* of each side passes through a foramen in the transverse partition of the sphenethmoid on its way from the organ of smell in the nasal capsule. The *second nerve*, which serves the eye, enters the skull through a conspicuous opening on each side in the middle of the sphenoidal region. The *third and fourth nerves* have each a minute foramen in the side of the same region. The *fifth and seventh nerves* pass through a large common opening on the under side of the skull, situated in a notch in the prootic bone mentioned below. The foramen for the *sixth nerve* is a small opening between those for the second and for the fifth and seventh. The *eighth nerve* enters from the inner part of the ear by an opening in the wall between the cranium and the auditory capsule. A foramen for the *ninth and tenth nerves* is situated in the exoccipital bone, at the side of the occipital condyle.

The nasal capsules are a pair of irregular, mainly cartilaginous enclosures continuous with the front end of the cranium. Only their hinder part is ossified, and this forms that part of the sphenethmoid which lies in front of its transverse partition. The wall between the two capsules is known as the *mesethmoid.* Through these capsules run the passages from the nostrils to the mouth, and each of them has therefore an opening above and below. Each

bears two membrane bones, one on its upper side and one beneath. The upper bone is known as the *nasal*, and is shaped like the outline of a pear, with the stalk directed outwards. The lower bone is the *vomer*. It is of irregular shape and carries a patch of teeth which project through the skin of the roof of the mouth.

The auditory capsules are blocks of cartilage continuous with that of the cranium. Each contains a complicated space, the *cartilaginous labyrinth*, which lodges a structure known as "the membranous labyrinth of the ear." Part of the front of the capsule is ossified to form the *prootic* bone. Above these there abuts on its outer side a T-shaped membrane bone known as the *squamosal*, which touches it by one limb of the cross-piece of the T, the main limb being directed outwards and downwards. At one spot on the outer side of the capsule the cartilage fails and the labyrinth is covered only by membrane. This gap is known as the *fenestra ovalis*, and from it a slender rod of bone and cartilage, the *columella auris*, runs to the drum of the ear, so that when the latter is thrown into vibrations by sound waves its movements are transferred by the columella to the labyrinth through the membrane.

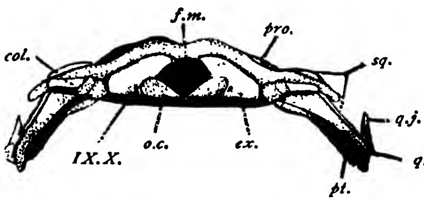


FIG. 16.—The skull of a frog, seen from behind.

col., Columella; *ex.*, exoccipital; *f.m.*, foramen magnum; *o.c.*, occipital condyle; *pro.*, prootic; *pt.*, pterygoid; *q.*, quadrate; *q.j.*, quadratojugal; *sq.*, squamosal; *IX.X.*, foramen for ninth and tenth cranial nerves.

The framework of the upper jaw is composed of two series of structures, an outer, which borders the opening of the mouth, and an inner, which supports the outer. The inner series is known as the *palato-pterygo-quadrate* on account of the parts of which it is composed. These are as follows. From the junction of the cranium with the nasal capsules there projects outwards a bar of cartilage, against the hinder, or orbital, side of which lies a

membrane bone known as the *palatine.*[1] At its outer end the cartilaginous bar turns backwards, and here another membrane bone, the *pterygoid*,[1] fits against its inner side. The pterygoid is Y-shaped, with the fork directed backwards, the inner branch of the Y abutting on the auditory capsule. The outer branch underlies the main branch of the squamosal, and between these two bony rods there projects outwards from the auditory capsule a rod of cartilage, the *quadrate*, continuous with the longitudinal bar. With the quadrate, held firm as it is by processes of the squamosal and pterygoid, articulates the lower jaw, for which the structures in question are said to form the *suspensorium*. The outer series of bones of the upper jaw begins with the *premaxilla*, a small membrane bone applied to the front of the nasal capsule, on to whose upper surface it sends a process. The two premaxillæ meet in the middle line, forming the tip of the upper jaw, and each of them bears a row of teeth. Behind the premaxilla, on each side, another membrane bone, the *maxilla*, continues the edge of the jaw. The maxilla is a long slender bone which bears a row of teeth. Along the greater part of its length it is supported by the nasal capsule and pterygoid, but the hinder part lies free till it

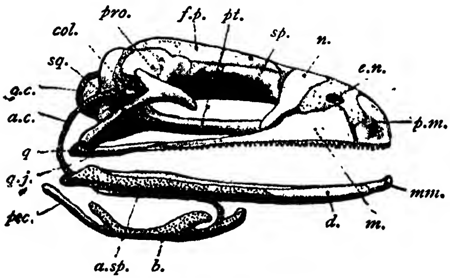


FIG. 17—The skull of a frog, seen from the right side.

a.c., Anterior cornu of hyoid; *a.sp.*, angulo-splenial; *b.*, body of hyoid; *col.*, columella; *d.*, dentary; *e.n.*, external narial opening; *f.p.*, fronto-parietal; *m.*, maxilla; *mm.*, mentomeckelian, *n.*, nasal; *o.c.*, occipital condyle; *p.c.*, posterior cornu of hyoid; *p.m.*, premaxilla; *pro.*, prootic; *pt.*, pterygoid; *q.*, quadrate; *q.j.*, quadratojugal; *sp.*, sphenethmoid; *sq.*, squamosal.

[1] The palatine and pterygoid are cartilage bones in most of the animals in which they occur. In the frog the cartilage bone is replaced in development by membrane bone.

meets a small membrane bone, the *quadratojugal*, which connects it with the quadrate.

The lower jaw or *mandible* consists of two halves united in front by a ligament. Each half is a curved rod of cartilage, known as *Meckel's cartilage*, ossified at the end to form the small *mentomeckelian* bone, and almost completely ensheathed by a couple of membrane bones, the *angulo-splenial* within, and the *dentary* without. The latter does not, as its name would imply, bear teeth, the frog having no teeth in the lower jaw. At the near end or *angle* of the jaw the dentary bears a small knob or *condyle*, which fits into a hollow, known as the *mandibular fossa*, on the end of the quadrate.

The hyoid is a flat structure in the floor of the mouth. It consists of a wide *body* with two short processes on each side and two longer processes, the *cornua*, at each end. The *anterior cornua* are very long and slender and curve backwards at the sides of the body and then upwards to be attached to the sides of the auditory capsules. The *posterior cornua* are shorter and stouter and project backwards at the sides of the windpipe. They are the only ossified parts of the hyoid, the remainder consisting of cartilage.

The following table represents in a summary form the architecture of the skull:

Regions of skull.	*Cartilage bones.*	*Membrane bones.*
Cranium	Exoccipitals Sphenethmoid (part)	Fronto-parietals. Parasphenoid.
Nasal Capsules	Sphenethmoid (part) Mesethmoid	Nasals. Vomers.
Auditory Capsules	Prootics	Squamosals.[1]
Visceral Arches—		
Upper jaw	(Palatines[2]) (Pterygoids[2])	Premaxillæ. Maxillæ. Quadratojugals.
Lower jaw	Mentomeckelians	Angulo-splenials. Dentaries.
Hyoid	Posterior cornua	None.

[1] Attached to auditory capsules but not belonging to them.

[2] Cartilage bones in many animals. In the frog only the first rudiment is cartilage bone and this is replaced in development by membrane bone.

Limb Girdles.

The *shoulder girdle or pectoral arch* is a flat structure of cartilage and bone embedded in the body-wall of the forepart of the trunk, which it almost encircles. It consists of two similar halves, one on each side of the body, united below but separate above, where they are bound by muscles to the backbone. Each half is composed of an upper *scapular portion or shoulder blade* and a lower *coracoid portion.* The uppermost part is a broad, flat plate lying on the back known as the *suprascapula.* A great part of this consists of cartilage stiffened by calcareous matter, but it has a narrow rim of plain cartilage and a core of true bone[1] lies at its outer end, where it joins the *scapula,* a narrower but stouter bone lying at the side of the body. A forward projection from this bone is known as the *acromion process.* To the lower end of the scapula is attached the coracoid portion of the girdle. This is a plate of cartilage and bone lying on the under side of the body in the breast region and pierced by a wide oval space called the *coracoid fontanelle.* Behind the fontanelle lies the stout *coracoid bone*; in front is a narrow strip of calcified cartilage, the *precoracoid,* continuous with another strip known as the *epicoracoid* which forms the inner border of its half of the girdle and lies against its fellow in the middle line. This junction of the two halves of the girdle is known as its *symphysis.* The only membrane bones in the girdle are the *clavicles.* They are a pair of slender structures which overlie the precoracoid cartilages. Each sends forward a prolongation beside the acromion process. At the junction of the scapula and coracoid bones is the

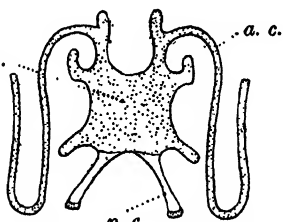


FIG. 18.—The hyoid apparatus of a frog.

a.c., Anterior cornua ; *b.*; body; *p.c.*, posterior cornua.

[1] The structure of bone has already been alluded to. It will be more fully described together with that of cartilage in a later chapter. Bone differs from cartilage not in the mere presence of calcareous matter, but in structure and composition.

glenoid cavity, a hollow, lined by cartilage, on the hinder edge of the girdle, into which fits the head of the humerus or bone of the upper arm.

To the ends of the epicoracoids, before and behind the girdle, are attached certain structures which are analogous to the *breastbone or sternum* of other animals. In front is a bone known as the *omosternum*, bearing at its end a small plate of cartilage, the *episternum*. Behind is the larger *xiphisternum*, bearing the broad, flat *xiphoid cartilage*.

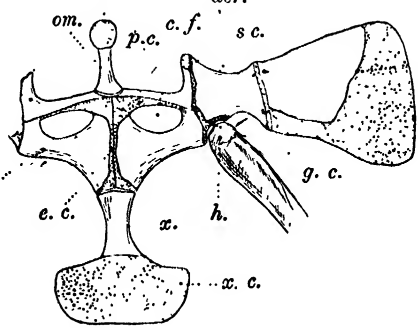


FIG. 19.—The shoulder girdle of a frog, seen from below, with the right scapula removed.

acr., Acromion process; *c.f.*, coracoid fontanelle; *cl.*, clavicle; *cor.*, coracoid; *e.c.*, epicoracoid; *ep.*, episternum; *g.c.*, glenoid cavity; *h.*, head of humerus; *om.*, omosternum; *p.c.*, precoracoid; *sc.*, scapula; *sup.*, suprascapula; *x.*, xiphisternum; *x.c.*, xiphoid cartilage.

The *hip girdle or pelvic arch* lies at the hinder end of the trunk in a position similar to that occupied in front by the shoulder girdle, which it also resembles in consisting of two halves, each composed of several pieces, joined below in a symphysis. Its shape, however, is very different; it is connected with the backbone not solely by muscles, but also by joints or articulations with the large transverse processes of the sacral vertebra; it bears no bone comparable with the clavicle, and there are in connection with it no unpaired structures such as the sternum. The greater part of each half consists of a long slender bone, the *hip-*

bone or ilium corresponding in position to the scapular part of the shoulder girdle, which runs downwards and backwards from the sacral vertebra, curving inwards on the under side of the body to join its fellow. The junction is enlarged into a flattened mass by the addition of several elements which are more distinct while they are being formed in development than they are in the adult. Behind lies a ridge of bone known as the *ischium*, which consists at first of two parts, one belonging to each half of the girdle. A slight groove marks the limits of this bone. In front a similar ridge, not marked off from the ilium, is known as the *pubis*, and represents a pair of pubic bones found in certain other animals, though its relation to the bones so called in man is uncertain. Ventrally, between the pubis and the ischium, lies a triangular piece of calcified cartilage, the *postpubic cartilage*. In each of the flat sides of the mass formed by the union of these structures is a round hollow, the *leg-socket or acetabulum*, into which fits the head of the thigh-bone.

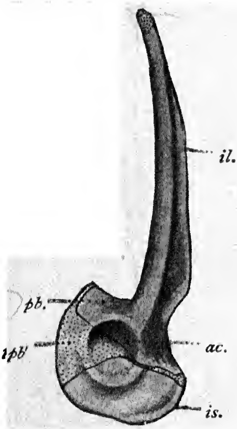


FIG. 20.—The hip girdle of a frog, seen from the left side.

ac., Acetabulum; *il.*, ilium; *is.*, ischium; *pb.*, pubic region of ilium; *pb'.*, post-pubic cartilage.

Limbs.

The upper arm contains a single bone, the *upper arm bone or humerus*. This consists of a stout shaft, swollen at each end, and bearing on its inner side a ridge known as the *deltoid ridge*. The swelling at the upper end is the *head*, and fits into the glenoid cavity of the shoulder girdle. That at the lower end, the *trochlea*, is more irregular in shape and serves for the articulation of the *forearm bone or radio-ulna*. In man, and in most animals whose limbs are built upon the same plan as those of the frog, the forearm contains two bones, the *radius* and the *ulna*, and traces of the fusion of these can clearly be seen in the frog. The radius is the inner of the

two components of the bone, but its upper end lies partly in front of the ulna.[1] The upper end of the radio-ulna is hollowed to receive the humerus at the elbow-joint, behind which it projects as the *elbow-bone or olecranon process*. The wrist consists of six small *carpal bones* arranged in two rows across the limb. Those of the first row are named according to their position *radiale*, *intermedium*, and *ulnare*.[2] The second row contains in the early stages of its development five bones, called *distal*

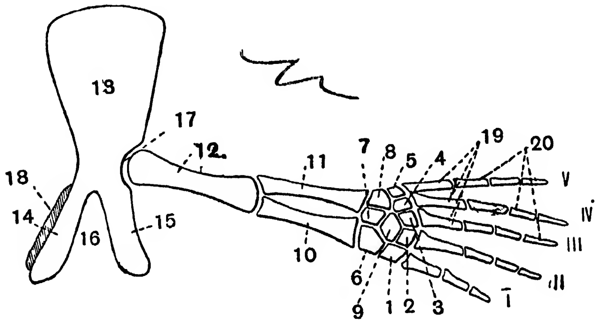


FIG. 21.—A diagram to illustrate the structure of the limbs and girdles of pentadactyle animals.

1–5, Distal carpals or tarsals; 6, radiale or tibiale; 7, intermedium; 8, ulnare or fibulare; 9, centrale; 10, radius or tibia; 11, ulna or fibula; 12, humerus or femur; 13, scapula or ilium; 14, precoracoid or pubis; 15, coracoid or ischium; 16, coracoid fontanelle or obturator foramen; 17, glenoid cavity or acetabulum; 18, clavicle; 19, metacarpals or metatarsals; 20, phalanges; I.–V., digits.

carpals, corresponding to five digits, but in the adult frog the third, fourth, and fifth of these have fused.[3] The palm contains five *metacarpal bones*. The first digit is wanting, but the second and third have each two bones and the fourth and fifth three, according to the number of their joints. These bones are called *phalanges*.

[1] See p. 274.
[2] For the names of the corresponding bones in the rabbit and man, see p. 275.
[3] In many animals (but not in man) a bone known as the *central* or *centrale* lies between the two rows of bones of the wrist.

The bones of the leg correspond closely to those of the arm. The *thigh-bone or femur* has a long, slender, slightly curved shaft with a rounded *head* to fit into the acetabulum and a wide *condyle* for articulation with the *shank-bone, os cruris, or tibio-fibula.* The latter, like the radio-ulna, corresponds to two bones in man and many other animals, showing traces of being formed by the fusion of an inner or anterior *shin-bone or tibia* and an outer or posterior *fibula.* The ankle, like the wrist, consists of two rows of bones, which are here called *tarsals.* The first row contains two bones, the *tibiale, astragalus, or talus* and the *heel-bone, fibulare, or calcaneus.* These bones are joined at each end by a piece of cartilage. The second row consists of two small *distal tarsals.* The metatarsus contains six *metatarsals,* one minute and corresponding to a small extra toe, the *prehallux or calcar,* which lies inside the first toe or hallux, but does not project from the foot. The calcar has one phalanx, the first two toes have each two, the third and fifth toes three, and the fourth toe, which is the longest, has four.

It will be seen that the fore- and hind-limbs and girdles are built upon a common plan. The skeleton of this is shown in Fig. 21. It may be traced in all animals which are *pentadactyle*—that is, have fingers and toes. Neither of the limbs of the frog conforms to it exactly.

Muscles.

The movements of the body and of its organs are brought about by means of a tissue known as *muscle.* This tissue is classed according to its function as *voluntary* when it is under the direct control of the will and *involuntary* when it is not under such control. Involuntary muscle generally forms part of the wall of some internal organ such as the stomach, bowel, bladder, or heart, and by its contraction brings about changes in the width of this organ and thus movement of the fluid it contains. Voluntary muscle is usually found in the form of distinct organs or *muscles,* which are attached at their ends to two parts of the skeleton and by their contraction change the relative position of these parts and thus of the regions of the body which they support. Sometimes the end of a muscle may be attached by a stout band or *aponeurosis* of connective tissue to another muscle

There is, generally speaking, also a difference in fine structure between voluntary and involuntary muscle, but we shall postpone discussion of this for the present. A muscle has a *belly* of muscular tissue which is attached by *tendons* of a peculiar kind of connective tissue. One of the two attachments is called the *origin*, and this is made to a relatively fixed part; the other, called the *insertion*, is made to a more movable part. Parts of the skeleton which are thus movable upon one another must be provided with *joints*. When the amount of movement which is possible is small, the joint consists of an intervening layer of cartilage

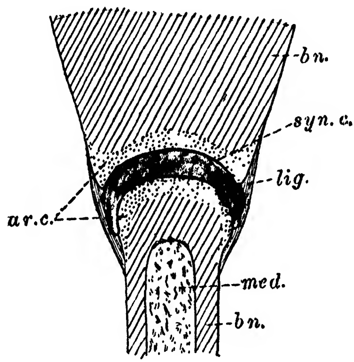


FIG. 22.—A diagram to illustrate the structure of "perfect" joints.

ar.c., Articular cartilage; *bn.*, bone; *lig.*, ligament; *med.*, medulla or marrow; *syn.c.*, synovial capsule

or ligament, and is said to be *imperfect*. This kind of joint is found, for instance, between the bones of the frog's shoulder girdle. When free movement is possible there is a *perfect joint*. Here a convex surface of one structure plays within a concave surface of another, the two surfaces being separated by a fibrous bag, the *synovial capsule*, which contains a watery fluid, the *synovia*, and serves as a cushion. Outside the joint, ligaments hold the movable pieces together. The muscular system of the frog is complicated, and we shall therefore only give an

outline of its general arrangement and mention a few of the more important muscles.

The following table sets forth the *general arrangement of the muscular system*:

A. MUSCLES OF THE TRUNK.

1. *Muscles of the lower side.*
   a. *Muscles of the Belly.*
      e.g. *Rectus abdominis*, a wide band running along the belly, divided lengthwise down the middle by the connective tissue *linea alba* and transversely by *tendinous intersections.*
      Obliquus externus, a broad sheet at each side of the body, arising from an aponeurosis known as the *dorsal fascia* which covers the muscles of the back, and inserted into the linea alba above the rectus abdominis.
      Obliquus internus and *transversus*, muscular sheets within the external oblique.
      By their contraction all these muscles lessen the size of the body cavity and compress the organs within it.
   b. *Muscles of the Breast Region.*
      e.g. *Pectoralis*, large and fan-shaped, inserted into the deltoid ridge of the humerus and consisting of a *sternal portion* which arises from the pectoral girdle, and an *abdominal portion* which arises from the aponeurosis at the side of the rectus abdominis. It draws down the arm.
      Coraco-radialis, arising from the coracoid and inserted into the upper end of the radius. It bends the arm.
2. *Muscles of the Back.*
   a. *Muscle inserted into the Lower Jaw.*
      Depressor mandibulæ, triangular, arising from the suprascapula and inserted into the angle of the lower jaw, which it draws downwards and backwards, thus opening the mouth.
   b. *Muscles inserted on the Fore-Limb.*
      e.g. *Latissimus dorsi*, triangular, arising from the dorsal fascia and inserted into the deltoid ridge. It draws back the arm.
      Infraspinatus, in front of and similar to the latissimus dorsi. It raises the arm.
   c. *Muscles inserted into the Shoulder Girdle.*
      e.g. *Levator scapulæ*, arising from the skull and inserted into the under side of the suprascapula, which it draws forward.
      Serratus, arising from the little knobs on the transverse

processes of the vertebræ which represent the ribs, and inserted into the under side of the suprascapula, which it draws backwards, outwards, or inwards according to the division which is contracted.

d. Muscles inserted into the Hind-Limb.

e.g. *Glutæus*, arising from the ilium and inserted into the femur, which it rotates inwards.

e. Muscles inserted into the Hip Girdle.

e.g. *Coccygeo-iliacus*, arising from the urostyle and inserted into the ilium, which it holds firm as a fulcrum for the movements of the hind-limb.

f. Muscles of the Backbone.

e.g. *Longissimus dorsi*, a band running the whole length of the back, divided by tendinous intersections, which are attached to the transverse processes, and inserted in front into the skull. It straightens the back.

B. MUSCLES OF THE HEAD.

1. *Muscles underneath the Head.*

e.g. *Sternohyoid* from hyoid to pectoral girdle.
Geniohyoid from hyoid to chin.
Hyoglossus from hyoid to tongue.
Petrohyoid from hyoid to auditory capsule.
Mylohyoid, submandibular, or submaxillaris, a sheet of muscle running from side to side of the lower jaw.

These muscles alter the position of the floor of the mouth.

2. *Muscles of the Lower Jaw.*

e.g. *Temporalis and masseter*, arising from the skull and inserted into the lower jaw, which they raise.

3. *Muscles of the Eyeball.*

Rectus superior, r. inferior, r. externus (or *lateralis*), *r. internus* (or *medialis*), arising from the skull in the hinder part of the orbit and inserted into the eyeball.

Obliquus superior and o. inferior, arising from the skull in the front part of the orbit and inserted into the eyeball.

These muscles will be more fully described in the chapter on the dogfish.

C. MUSCLES OF THE FORE-LIMB.

1. *Muscles for the Upper Arm.*

e.g. *Deltoideus*, arising from the scapula and inserted into the humerus. It raises the arm.

2. *Muscles for the Fore-Arm.*

Triceps brachii or anconæus, arising from the scapula and humerus, and inserted into the upper end of the ulna. It straightens the arm.

There is no *Biceps* muscle in the arm of the frog.

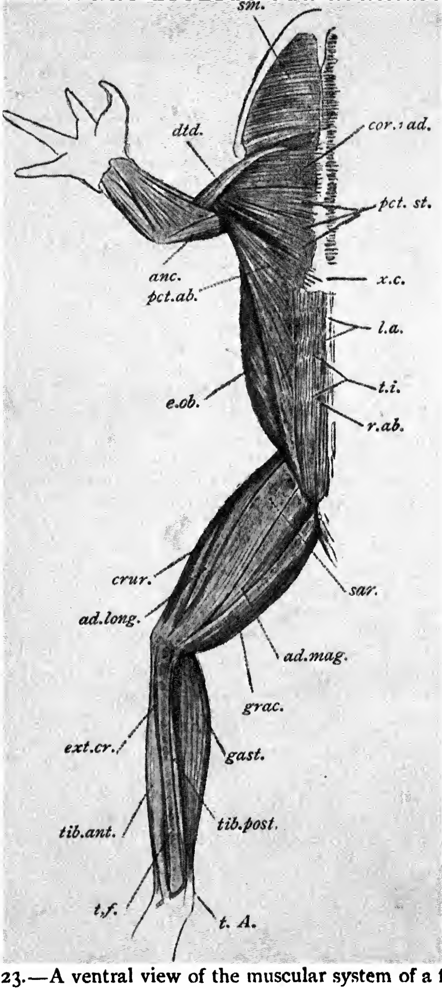


FIG. 23.—A ventral view of the muscular system of a frog.

ad.long., Adductor longus; *ad.mag.*, adductor magnus; *anc.*, anconæus; *cor.rad.*, coraco-radialis; *crur.*, crureus; *dtd.*, deltoid; *e ob.*, external oblique; *ext.cr.*, extensor cruris brevis; *gast.*, gastrocnemius; *grac.*, gracilis; *l.a.*, linea alba; *pct.ab.*, abdominal part of the pectoral muscle; *pct.st.*, sternal part of the same; *r.ab.*, rectus abdominis; *sar.*, sartorius; *sm.*, mylohyoid; *t.i.*, tendinous intersections; *t.A.*, tendo Achillis; *t.f.*, tibiofibula; *tib.ant.*, tibialis anterior; *tib.post.*, tibialis posterior; *x.c.*, xiphoid cartilage.

Movements.

The formation of a pseudopodium begins with a slight outflowing of the ectoplasm, into which the endoplasm presently flows. The projection continues to grow by the flow of more protoplasm into it for a varying time, and locomotion is brought about by the persistent lengthening of one pseudopodium till the bulk of the body has been transferred into it. During this time it is throwing out subsidiary pseudopodia in various directions. Before very long, however, the main flow is directed into one of these and the animal

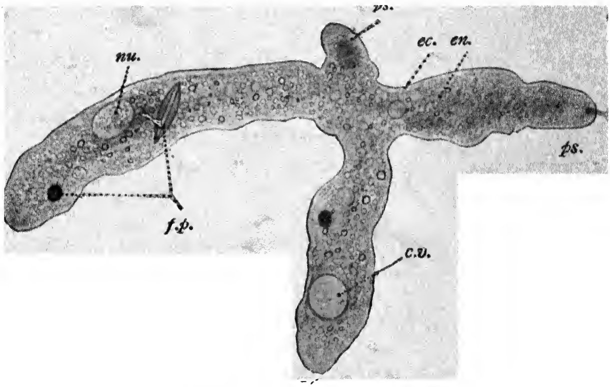


FIG. 71.—*Amœba proteus*, highly magnified.

c.v., Contractile vacuole; *ec.*, ectoplasm; *en.*, endoplasm; *f.p.*, food particles; *nu.*, nucleus; *ps.*, pseudopodia.

moves in another direction, the stream in the older pseudopodia setting backward into the body until they disappear. The flow of the endoplasm is always swifter in the middle of a pseudopodium than at the sides. It will be seen that we have here an example of *contraction*, as the word is used in Biology, the shape of the mass of protoplasm being changed by the transference of material, but the size remaining the same. The throwing out of a pseudopodium is not brought about merely by a flowing of the protoplasm. The ectoplasm has a certain toughness and its surface is sticky. After the first outflow of ectoplasm has begun to form the pseudopodium, as the endoplasm flows into it, the ect

plasm is drawn forward over the back, being lifted up behind the animal and laid down in front. Where it is in contact with the ground its stickiness causes it to adhere. All this can be seen by dropping minute particles of soot on to the back of the animal. They are found to stick to the surface, pass forwards till they reach the ground in

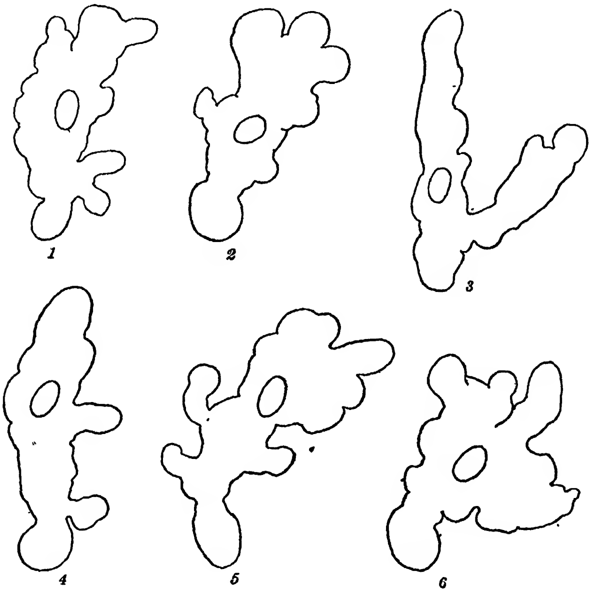


FIG. 72.—Successive changes in shape of an individual of *Amœba proteus*, drawn at intervals of two minutes.

front of a pseudopodium, and then remain stationary whil the animal moves forwards over them, till they come to li at its hinder end, when they are lifted and carried forward again over the back. An indiarubber bag filled with wate and rolled forward over a flat surface illustrates well th movement of *Amœba*. During the movements the conten of the endoplasm—nucleus, food particles, etc.—are carrie about freely from place to place in the body, but the co

tractile vacuole adheres to the inner surface of the ectoplasm and moves with it. The constant changes of position of internal bodies is one of the arguments which support the foam theory of the structure of protoplasm (see p. 85) against theories which demand the existence in it of a meshwork of fine threads, and an examination under high powers of the microscope confirms this by revealing appearances similar to those found in certain artificially made foams.[1] This is especially noticeable in surfaces, such as

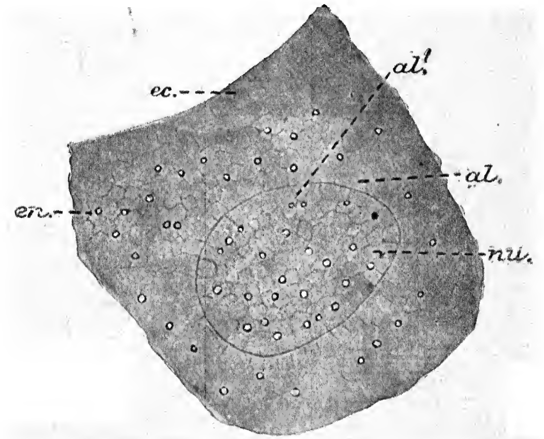


FIG. 73.—Part of an *Amœba proteus*, very highly magnified, showing the foam-like appearance in the protoplasm, and some of the granules which it contains.

al., Regular layer of compartments in the cytoplasm around the nucleus; *al'*, similar structures in the outer layer of the nucleus; *ec.*, ectoplasm; *en.*, endoplasm; *nu.*, nucleus.

those where the cytoplasm and nucleus are in contact. Each surface has a very regular row of minute bubbles known as the *alveolar layer*. A similar layer is said to exist in the ectoplasm, the outer walls of its bubbles forming the surface, but this is doubtful. The surface behaves like an exceedingly fine skin. It is known as

[1] Such a foam may be made by mixing together rancid oil and salt and placing little droplets of the mixture in water.

the *pellicle*, and is believed to be rich in fatty substances. Artificial foams can even be induced to carry out movements which in their general features resemble contraction. It should be noted, however, that the special features of the contraction of *Amœba* are not found in them.

Nutrition.

Amœba feeds on small organisms, which it *ingests* by surrounding them with outgrowths of its protoplasm and so engulfing them. Ingestion usually takes place at the hinder end of the animal. The space in the body which the prey comes to fill would thus be lined with ectoplasm, but the ectoplasm here becomes absorbed into the surrounding endoplasm, so that it is clear that there is no essential difference between the materials which compose these layers. There is then secreted around the food particle a layer of water containing substances which kill it and digest its nourishing part. The reaction of this fluid is acid at first, but probably later becomes alkaline. The space containing the digestive juice is known as a *food vacuole*. The chief food of *Amœba* is protein. It is said also to digest carbohydrates, but not fat. The dissolved substances are incorporated and the undigested parts are *egested* by the simple process of being left behind as the animal flows along.

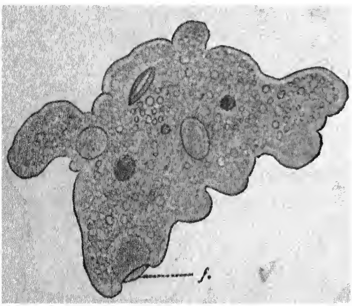


FIG. 74.—*Amœba proteus* in the act or ingesting *f*, a small vegetable organism which is being swallowed.

Irritability, Automatism and Conductivity.

The protoplasm of *Amœba* is irritable, automatic, and conducive. Its *irritability* is not, as in higher animals, specially developed in sense organs, but that this property exists in it is shown in various ways. If it be stimulated by passing an electric shock through a drop of water in which it has been placed, it will contract into a mass without pseudopodia. If it be pricked with the end of a fine thread of glass it will draw back and flow away. In this case the

formation of a pseudopodium in a region of the body other than that which has been stimulated shows the presence of *conductivity*. Again, it does not swallow every particle it comes across, but chooses those that either contain nourishing substances or, being in motion, are probably alive and therefore fit for food. By an unkind deception of this "sporting instinct," it may be induced to capture and swallow moving particles of glass. Its mode of seizing food is not fixed, but adjusted with an uncanny appearance of intelligence to the nature and behaviour of the prey of the moment, which it dogs with perseverance and resourceful changes of method. How much it can see is doubtful. It will move towards light, but does not appear to perceive a particle of food better in the light than in the dark. Yet it seems to become aware at a short distance of a particle of food even when the latter is insoluble, and therefore incapable of being smelt. All this shows that it receives from foreign bodies stimuli of different kinds, and discriminates between them. In contrast to these instances, many of the actions of the animal cannot be traced to any stimulus, and must therefore be classed as *automatic* in the sense in which we have used that word.

Excretion and Respiration.

The contractile vacuole is probably an excretory organ. Waste products are shed into its cavity and thus removed from the body when its contents are discharged.[1] Water probably enters all over the surface of the animal and is collected into the contractile vacuole together with the water produced during the metabolism of the animal. The water must bring with it dissolved oxygen, and thus the contractile vacuole aids respiration. At the same time it seems likely that the whole surface of the body may serve to some extent both for respiration and for excretion.

Depression.

Unfavourable conditions of life may bring about a disease known as *depression*, in which the nucleus of the *Amœba* is enlarged and the various functions become deranged. This disease, however, is more familiar and has been more closely investigated in some other minute animals, as, for instance, in *Paramecium* (p. 133).

[1] The nitrogenous waste product uric acid has been found in the contractile vacuole of organisms related to *Amœba*.

Encystment. In certain circumstances *Amœba* withdraws its pseudopodia and becomes a rounded mass which secretes about itself a tough case or *cyst*.[1] In this it lies dormant and can survive the drying or freezing of the pond in which it lives or be transferred in mud to other ponds. We have here an instance of a widespread phenomenon known as *suspended vitality*, and found, for in stance, in seeds and in frozen tissues (see p. 87). . The exact condition of the protoplasm in such cases is a mystery, but no vital processes can be detected, and it has been shown by experiments on seeds that, if they be kept perfectly dry, not even respiration takes place. We must conclude that life, regarded as a process, has slowed down and, at least in some cases, ceased, but that the protoplasm retains the power of resuming it in certain circumstances. At death, on the other hand, the protoplasm passes into a condition in which it will indeed remain intact in suitable circumstances (as when it is frozen) but has lost the power of resuming life. Many other small freshwater animals can pass into a state of suspended vitality, and dried mud brought to England from places thousands of miles away will often, on being placed in water, give rise to numerous creatures that thus lay dormant in it. The artificial suspension of vitality in tissues by freezing has been made use of with very striking results in surgery, portions of living tissue removed from one body being preserved for days in a state of suspended vitality by cold and afterwards successfully grafted in to repair injuries in another body. In this way, for instance, the cornea taken from an eye that had for

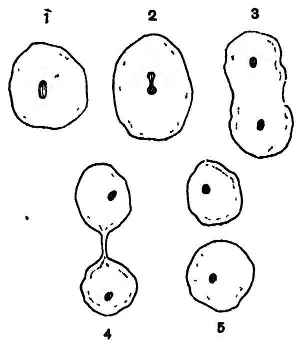


FIG. 75.—A diagram of the fission of *Amœba*. The dark spots represent nuclei.

[1] It is doubtful whether the resting cyst of *A. proteus* has been seen. Such cysts are known in other kinds of *Amœba*, and in spore formation (see p. 119) *A. proteus* shows that it has the power of encystment.

some other reason been removed from a human patient has been used after several days to replace the same tissue in another man in whom it had been injured.

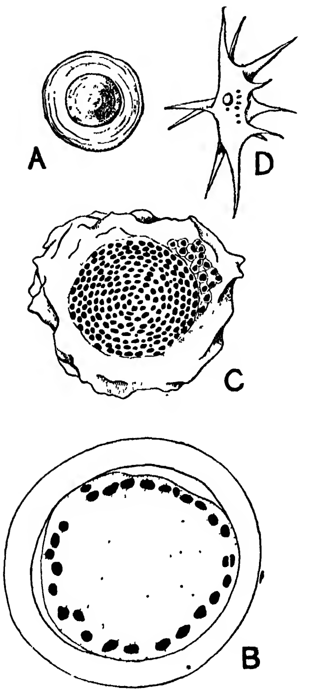


FIG. 76.—Multiple fission of *Amœba proteus*.—After Scheel.

A, *Amœba* encysted; *B*, section of a cyst in which numerous nuclei have been formed; *C*, surface view of a ripe cyst in which the spores are beginning to separate and the cyst wall to break up; *D*, a single spore highly magnified.

Reproduction. *Amœba* reproduces by the process known as *binary fission*, in which first the nucleus and then the cytoplasm parts asunder into two halves, each of which appears, at all events, to differ from the parent in nothing but size. In some species of *Amœba* the division of the nucleus is amitotic, but in *Amœba proteus* there is a peculiar kind of mitosis in which the place of centrosomes is taken by a mass of clear protoplasm at each end of the nucleus. These masses are known as *pole plates* and arise within the nuclear membrane, which does not break up during division as in ordinary mitosis.[1] After the division of the nucleus the cytoplasm flows apart into two bodies, each of which contains one of the daughter nuclei. The new bodies are at first connected by a bridge of protoplasm, but this becomes narrower until it breaks through and two new individuals come into being. Another kind of fission, known as *multiple fission or spore formation*, has been seen in

[1] Not all the chromatin in *Amœba proteus* forms chromosomes. That of the outer part of the nucleus behaves as in amitotic divisions. There is an inner mass which alone takes part in the mitotic process.

Amœba proteus. During the winter the animal encysted and its nucleus divided amitotically till a very large number (some 600) of small nuclei had been formed. These passed to the surface of the cytoplasm, which gathered into a little mass around each of them. The cyst wall was now dissolved and the little individuals or *spores* escaped as small *Amœbæ* with fine, pointed pseudopodia unlike the blunt processes of the adult, a residual mass of unused cytoplasm being left behind. The young forms grew and became transformed into adults.

Multinucleate Amœbæ.

Conjugation has not been seen in *Amœba proteus.*[1] The animal does, however, occasionally undergo a process known as *plasmogamy*, in which the cytoplasm of several individuals fuses, forming a single mass which contains several nuclei. Such a mass is known as a *plasmodium.* The macrophages formed by leucocytes (p. 101) are plasmodia. Quite another kind of multinucleate body is found in certain *Amœba*-like animals known as *Pelomyxa*, where two or more nuclei are formed by the division of a single nucleus. These may be compared with cœnocytes.[2]

Amœba and the Cell Theory.

Our survey of the life and structure of *Amœba* has shown us that it must be regarded as an organism in no way inferior to the frog in its fundamental powers. It is irritable and automatic, undergoes katabolism, contracts, conducts, does chemical work, secretes and excretes, respires, incorporates food, and reproduces. It differs from the frog only in the extreme simplicity of its structural organisation, possessing as it does no obvious permanent organs except the cytoplasm, nucleus, and contractile vacuole, and besides these only the temporary organs known as ectoplasm, endoplasm, and pseudopodia. It has no tissues, unless we

[1] Supposed instances of conjugation in *A. proteus* have been described but it has not been shown that the gametes belonged to this species Conjugation is known in other kinds of *Amœba.*

[2] They are not cœnocytes, which are specialised parts of the protoplasm of the body, whereas *Pelomyxa* is a whole body. Groups of similar, unseparated energids are known as *syncytia.* They may be *plasmodia*, formed by the union of free energids, or *symplasts*, formed by the division of the nucleus of a single energid. A symplast may be a *cœnocyte*, or the whole body of an organism.

regard the ectoplasm and endoplasm as tissues unprovided with special nuclei. In many points of structure and behaviour *Amœba* resembles closely the white corpuscles of the frog and more distantly the other cells of the frog's body. It is, in short, a self-contained mass of protoplasm with a nucleus — an isolated energid. For this reason it has been usual to regard it as a cell, and to call it a *unicellular organism*, and a theory known as the *cell theory* is widely held, on which the body of such an animal as the frog is said to be a colony of units, each comparable to a single *Amœba*, specialised for co-operation with the other cells of the body. But this theory is in reality an inversion of the facts. *Amœba* is a complete and independent organism comparable with the whole body of the frog. Its small size enables all the functions which the nucleoplasm performs to be carried out by a single nucleus. In the frog the size of the body makes necessary a large number of separate nuclei, and around each of these a part of the cytoplasm is more or less clearly segregated so that an energid (p. 85) is isolated. Such an energid isolated within the body is called a cell. Now the energids which are thus isolated as cells have not, as *Amœba* has, all the properties possessed by the body as a whole, but they have special qualities according to the functions which their position in the body demands. A cell is a portion of the body of a whole organism which has become specialised for the performance of particular functions, not, as the cell theory supposes, a whole organism which co-operates with other such organisms to form a body of a higher grade.

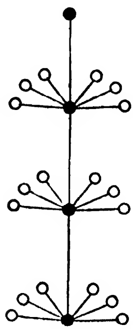


FIG. 77.—A diagram of the relation of germ and body substance in the frog. The dark circles represent germs, the light circles body cells. The germ gives rise in each generation to numerous body cells which remain together and eventually die, and also to germs (of which only one is shown in each generation). The germs leave the body and give rise each to a new group of body cells and new germs. Thus the germ substance is immortal, the body substance mortal.

Immortality of Amœba.

The difference between *Amœba* and the frog may be stated in another way. Viewed broadly, the formation of a germ by the frog is a separation of the body into two portions, one small—the germ—and another large, in which the individuality of the parent is continued. The parent consists mainly of energids which are specialised or differentiated for the performance of certain functions in the body, and are therefore unable to produce energids of other kinds. The germ is an energid which is not thus specialised, and may therefore be said to be "undifferentiated," though of course it has an organisation of its own. Now the substance of the specialised energids of the parent body is mortal: that is to say, sooner or later it undergoes natural death. But the germ contains substance which is immortal: that is to say, unless it be devoured, or starved, or poisoned, or fail to find a mate, or meet with some other fatality, it will not die a natural death, but in giving rise to a new adult organism gives rise also to another generation of germs, in which it continues to exist within the adult organism until the latter in turn sets free germs. The difference between *Amœba* and animals like it on the one hand, and higher animals like the frog on the other, lies in the fact that in the former there are no body-cells, but the whole body has the immortality of germ-substance.[1] The fission of *Amœba* is a separation of the body into two similar products, neither of which can be said, in virtue either of size or of mortality, to represent the parent. There are two offspring, but the parent has disappeared.

Entamœba.

Organisms known as *Entamœbæ*, closely related to *Amœba*, are parasitic within the body of man. The several kinds of *Entamœba* differ from *Amœba* only in that they have no contractile vacuole.[2] They have one or two large blunt pseudopodia, chiefly composed of ectoplasm, and they are all parasites, usually

[1] That is not to say that *Amœba* does not contain some substance comparable with the body-substance of the frog, but only that if such substance be present it is not contained in special energids which part from the germs and die.

[2] A contractile vacuole has been found in one organism which has been classed with the *Entamœbæ*.

in the alimentary canal of one of the backboned or, as they are called, "vertebrate" animals. *E. coli* lives in the upper part of the large intestine of man, feeding upon the bacteria which infest that region, and also upon the remains of the food of its host, which are probably of little value. It is harmless, and possibly sometimes even beneficial by keeping down the bacteria. Its life-history differs considerably from that of *Amœba proteus*. In the intestine it reproduces by binary fission and, it is said, also by multiple fission into eight little *amœbulæ*, and, as some of the individuals are being passed down the gut

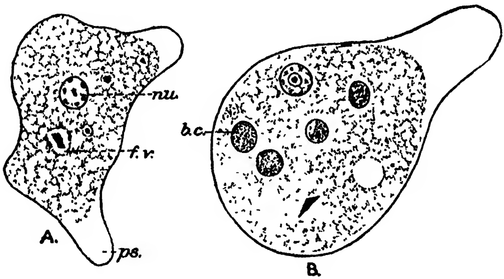


FIG. 78.—*Entamœba*.—After Fantham.

A, *E. coli*; B, *E. dysenteriæ*.

b.c., Ingested red blood corpuscle; *f.v.*, food vacuole, *nu.*, nucleus; *ps.*, pseudopodium.

and cast out with the fæces, certain of them undergo another process. In this the nucleus—after proceedings in which some of its chromatin is lost, while a large vacuole temporarily appears in the cytoplasm—forms eventually two nuclei while a cyst is being secreted around the body. The two nuclei in the cyst divide into eight. The ordinary *Entamœbæ* die in the fæces. So also do the cysts if the fæces dry, but if they remain moist until they reach water or human food and are swallowed by a man the cysts germinate in the intestine of the new host, the protoplasm dividing and emerging as little individuals each with a nucleus. By these the cycle is re-started.

Entamœba dysenteriæ, sometimes known as *E. histolytica*, also inhabits the human intestine. It varies much in size but reaches greater dimensions than *E. coli*, from which it also differs in being more active, having a distinct ectoplasm over the whole surface of the body, and taking up strongly, while still alive, the stain known as "neutral red." Unlike *E. coli* it bores through the mucous membrane of the intestine. This it does by making its pseudopodia of a sharper shape. It then penetrates the blood vessels in the same way, and is carried by the circulation to the liver, where it may set up abscesses. Its action on the intestinal wall causes dysentery. It feeds on tissues and also on red blood corpuscles, which *E. coli* does not. *E. dysenteriæ* is widespread in tropical and subtropical countries, and is the cause of much sickness and loss of life. An *Entamœba* of small size (*E. minuta*), and another known as *E. tetragena*, with a large chromatic central body or "karyosome" in the nucleus, are now known to be forms of *E. dysenteriæ* which arise in certain circumstances. Its life-cycle appears to differ from that of *E. coli* chiefly in the number of the amœbulæ, which, both in the free and in the encysted form, is only four. Binary fission takes place, and old, degenerating individuals are apt to undergo a process resembling budding.

CHAPTER VII

PARAMECIUM AND VORTICELLA. PROTOZOA

Paramecium: General Features.

Paramecium caudatum, the Slipper Animalcule, is a minute animal found in water in which dead leaves or other remains of organisms are decaying. The decay is brought about by bacteria, and upon these the slipper animalcules feed. A rich culture of *Paramecium* may be obtained by steeping hay in water, allowing it to decay, and adding to the *infusion* thus made mud or weeds from a freshwater pond which contains *Paramecium*. The animals may easily be seen with the naked eye as minute, greyish white, oblong creatures, shooting swiftly about in the water. The body of *Paramecium* is spindle-shaped, somewhat flattened on one side, and with one end blunter than the other. The flat side is called "ventral" and the blunt end is anterior. This end appears as though it had been twisted, so that a groove which it bears is spiral, starting in front on the left and curving round to the ventral side, where it is continued back in the middle line to within about a third of the length of the body from its hinder end. The groove is known as the *vestibule or peristome*: from its hinder end there passes backwards into the body a funnel-shaped gullet, the opening from vestibule to gullet being known as the mouth. The whole body is covered with fine protoplasmic threads of the kind known as cilia (see p. 89), by whose lashing the animal swims and gathers its food. The cilia are set at equal distances in rows, which run lengthwise in the hinder part of the body, but follow the spiral twist in front: they also line the gullet, where two or three rows of them are fused to form an *undulating membrane* which hangs from the roof. The cilia work regularly in waves, lashing back-

wards and driving the blunt end of the animal forwards, with a rotating movement like that of a rifle bullet owing to its spiral shape.

Eotoplasm and Endoplasm.

Like *Amœba*, *Paramecium* is non-cellular. There is a soft, granular endoplasm, and an ectoplasm which is much firmer than that of *Amœba* and gives the body its shape, but is elastic, so that the animal can bend and squeeze through narrow openings. The outermost layer of the ectoplasm is

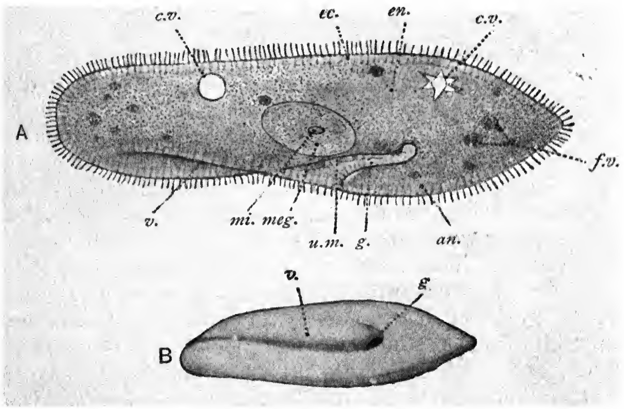


FIG. 79.—*Paramecium caudatum.*

A, An individual seen from the left side, highly magnified; *B*, a diagrammatic view of an individual from the ventral side, less highly magnified.

an., Position of temporary anus; *c.v.*, contractile vacuole; *ec.*, ectoplasm with trichocysts; *f.v.*, food vacuoles; *g.*, gullet; *meg.*, meganucleus; *mi.*, micronucleus; *u.m.*, undulating membrane; *v.*, vestibule.

a tough *pellicle*. Whether an "alveolar layer" (p. 115) underlies it, or is included in it, is uncertain. Below the pellicle comes the *cortex*, a thicker, clear layer of ectoplasm in which are embedded peculiar structures known as *trichocysts*. These are spindle-shaped bodies with a sharp point, and consist of some denser substance than the protoplasm. They are placed at right angles to the surface, with the point outwards. If the animal be strongly stimulated, as by a solution of some irritating substance, they suddenly elongate into threads and project from the body. The pointed end is harder than the rest and

remains unaltered as a spear-point. The trichocysts are supposed to be offensive or defensive weapons, but it has never been shown that this is the case. The pellicle is marked by rows of hexagonal pits, in the midst of each of which a cilium arises, while the trichocysts lie under the ridges which separate the pits. Each cilium consists of an axial thread and a covering layer continuous with the pellicle. The axial thread stops short of the tip of the cilium, which is pointed. Below the cilium the thread is continued inwards into the cortex, at the inner limit of which it bears a swelling known as the basal granule. The endoplasm contains numerous granules, some of which appear to consist of waste matters ready for excretion, while others may be stored nutriment. Glycogen is diffused through the endoplasm.

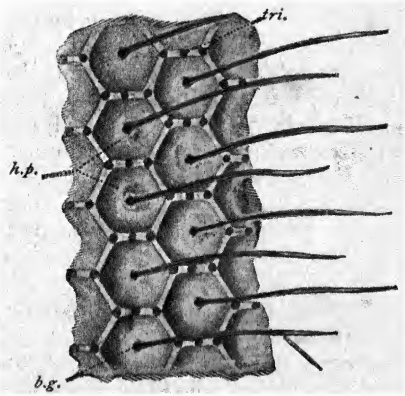


FIG. 80.—A portion of the surface of *Paramecium*, very highly magnified. —Partly after Bütschli.

b.g., Basal granule of a cilium; *ci.*, cilium; *h.p.*, hexagonal pits; *tri.*, trichocysts.

Nuclei. *Paramecium caudatum* has two nuclei. These, however, are not both of the same kind, like the nuclei of a *Pelomyxa* (p. 120), but consist of portions of the nucleoplasm specialised for different purposes. One is large and is concerned with the ordinary life of the body. This is known as the *meganucleus*. The other is small and is specialised for the purpose of conjugation. This is the *micronucleus*.[1] We may roughly compare the meganucleus with the nuclei of the body-cells of the frog and the micronucleus with the nuclei of the germs. The nuclei lie in the endoplasm above the gullet, the micronucleus in a cleft in the side of the meganucleus.

[1] The species known as *Paramecium aurelia* has two micronuclei.

Excretion. There are two *contractile vacuoles*, which lie in the cortex of the dorsal side, one towards each end. At its full size each is a large spherical space surrounded by from six to ten pear-shaped radiating canals, whose wide ends lie under it. These are the *formative vacuoles*. Contraction or "systole" affects only the central vacuole. After it has taken place, the formative vacuoles flow together at their inner ends and thus form the beginning of a new contractile vacuole, round which new canals appear, starting as mere slits and swelling to a pear shape by the enlargement of their inner ends. It is stated that the supposed excretory granules of the endoplasm collect near the formative vacuoles and are gradually dissolved. Over each contractile vacuole there appears to be a soft spot in the pellicle, through which the contents of the vacuole are discharged.

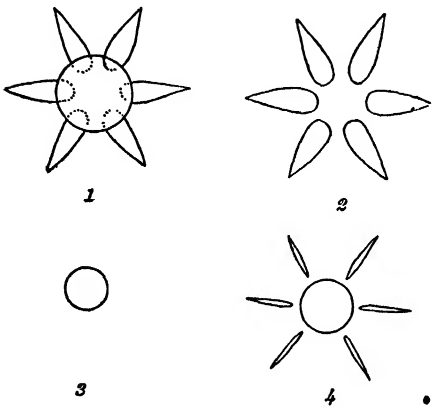


FIG. 81.—Successive stages of the contractile vacuole of *Paramecium*.

Nutrition. The food consists of bacteria and other minute organisms. These are drawn towards the mouth by the current set up by the cilia of the peristome and driven down the gullet by the working of the undulating membrane, which has a waving motion. The pressure of the water driven into the gullet with the food particles causes the naked endoplasm at the bottom of the gullet to bulge inwards, and into the space thus formed the food is forced. A drop of water containing the food particles is now pinched off by a contraction of the endoplasm and becomes a food vacuole, which

is carried by a streaming of the endoplasm around the body, passing first backward along the ventral side, then forward nearly to the middle of the body, then through several turns of a short circuit in this region of the body, and finally forward to the front end and back so as to complete the circuit of the body. During these wanderings the food is digested. The undigested remains are then expelled at a spot just behind the end of the gullet, where a passage through the ectoplasm, known as the *temporary anus*, is formed when it is required. Two periods may be recognised in the digestion. In the first period the water taken in with the food is being absorbed. Substances are secreted into the vacuole during this period which give it an acid reaction and kill the prey. In the second period an alkaline digestive juice is secreted into the vacuole, which increases in size. It appears that *Paramecium* cannot digest fat.

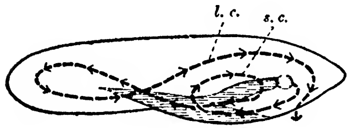


FIG. 82.—A diagram of the course of the circulation of the food vacuoles in *Paramecium*.

l.c., Long circuit; *s.c.*, short circuit.

Effect of Stimuli.

Like all other organisms, *Paramecium* is automatic (p. 11). Its incessant activity is spontaneous so far as immediate external stimuli are concerned, but is continually modified by such stimuli. The movements of *Paramecium* are much more active and definite than those of *Amœba*, and it is correspondingly easier to observe the effect of various stimuli upon the animal. These effects are of two kinds, upon the *rate* of movement and upon its *direction*. (1) Many acids, alkalies, salts, and other substances in dilute solutions cause an increase in the rate of motion owing to a more rapid working of the cilia. Moderate increase of temperature has the same effect. On the other hand, dilute solutions of narcotics, such as alcohol, ether, or chloroform, cause the cilia to work more slowly. All these reactions are probably merely the direct effects which such stimuli are known to have upon protoplasm. (2) In order that the effect of stimuli upon the direction of movement may be

observed, it is of course necessary that the stimulus should fall unequally upon different sides of the animal. It will then move to or from the direction in which the stimulus is strongest. This can be arranged by placing with a fine pipette a small drop of some solution in the vessel in which the animals are confined, or by heating or lighting one side only of the vessel. *Paramecium* will move towards weak acids or moderate warmth and away from alkalies, strong acids, warmth above 25° C., etc. Such actions are known as *tropisms.* It was believed that they could be explained in a simple way by the supposition that the effect of the stimulus in each case was either to slow or to quicken the working of the cilia on the side nearest to it, so that the animal was driven mechanically either towards or away from the stimulus by the unequal working of its cilia. What really happens, however, is by no means so simple. The effect of all stimuli to which *Paramecium* reacts naturally is to repel it. The animal on receiving a stimulus first withdraws, by a definite backward movement due to a reversal of the working of its cilia, from the stimulus. It then turns towards the dorsal side and swings the front end of its body round in a circle with that side outwards till it comes to point in some direction in which the stimulus is not acting, and in that direction it swims forwards. Thus its approach to conditions which appear to attract it is in reality due to an avoidance of the relatively less agreeable conditions which it meets in other directions during automatic wanderings. It behaves as if it were "trying" different directions of movement till one is found from which it is not repelled. It is claimed that in this procedure, known as the *method of trial and error*, the lowest animals, from *Amœba* upwards (see p. 117), show a rudiment of the intelligence of the higher.

Reproduction. *Paramecium* reproduces by binary transverse fission. The meganucleus divides amitotically, the micronucleus by a mitosis in which, as in that of *Amœba*, the nuclear membrane does not break up, and the place of centrosomes is taken by pole plates. Meanwhile a groove appears round the middle of the body and deepens till the cytoplasm is sundered into two, each half containing a daughter nucleus of each kind and one of

the contractile vacuoles. The two bodies formed by this fission are, like those of *Amœba*, asexually produced young, analogous to the buds of certain higher animals of which we shall speak in a later chapter (p. 161). Their development involves not only growth but also the remodelling of the body, since each of them lacks half the outward organs of the parent, while those which it has are too large for it. In a well-fed culture, division takes place two or three times a day, but if the animals be ill-nourished it is much less frequent, and if they be starved they cease to divide.

Conjugation. The conjugation of *Paramecium* is a remarkable process, being of a kind found only in this creature and in those which nearly resemble it. In it the animal, although in the absence of body-cells it resembles *Amœba*, forms in a peculiar way gametes which may be compared with those which are thrown off by the cellular body of the frog. The individuals which form the gametes are exactly alike and resemble normal individuals, except that they are somewhat smaller. As a rule, the process begins during the late hours of the night and lasts till the next afternoon. The details are as follows: Two individuals, which we will call *conjugants*,[1] lie side by side with their ventral sides together, the endoplasms becoming continuous in the region of the gullets, which degenerate. We may compare this with coition. The micronucleus of each conjugant leaves its normal position, lies free in the cytoplasm, and grows larger. It then divides twice, and three of its four products degenerate. During these divisions the number of chromosomes is halved, as it is in the gametogenesis of the frog (p. 107). though the details of the process differ in the two cases. The remaining micronucleus divides again, this time unequally, the smaller product being the *male pronucleus*, the larger the *female pronucleus*. At this stage we may regard each conjugant as containing two gametes, represented by the two pronuclei. These are analogous to an ovum and a spermatozoon, so that the animal may be said to be hermaphrodite. The true conjugation now takes

[1] They are often alluded to as gametes. This is incorrect. They are not gametes, but parents which form gametes.

place. The male pronucleus of each conjugant passes over into the other and fuses with the female pronucleus of the latter. The body which belonged to each conjugant comes thus to contain a micronucleus of mixed origin. It is, in fact, a zygote. The zygotes separate and are known as *exconjugants*. Immediately after separation the meganucleus degenerates, splitting up into shreds, which disappear. Thus the meganucleus resembles in the fact of its mortality the body-cells of the frog, though the body as a whole has the immortality of a germ-cell or an *Amœba*. Meanwhile the joint micronucleus of the exconjugant undergoes a development whereby nuclei of both kinds are provided. It divides three times successively, so that the body contains eight nuclei. After an interval the body divides into two, each half containing four nuclei, and after a further interval these halves divide, so that there are four individuals, each with two nuclei, one of which becomes a meganucleus and the other a micronucleus.

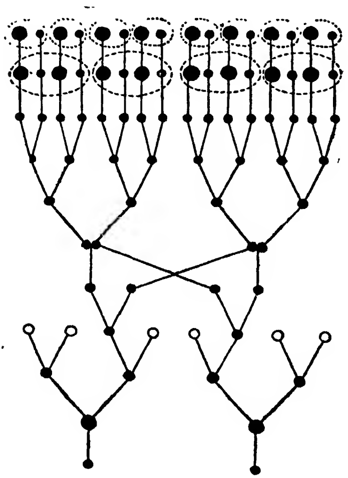


FIG. 83.—A diagram of the behaviour of the micronuclei during the conjugation of *Paramecium caudatum*. The white circles represent the portions which degenerate.

The conditions under which conjugation takes place in *Paramecium* have been, and are still, the subject of much investigation. Many points still remain to be cleared up, but certain results have now been reached. Conjugation generally occurs at the beginning of a falling off in the supply of food after a period of exceptional plenty that has brought about rapid multiplication. Thus it will often take

place in an infusion in which the bacteria, having used up the nourishment provided by the plant-remains, are falling off in numbers, and thus the *Paramecia*, after a plentiful supply of food, are beginning to experience dearth. But there are some races in which it is difficult to bring about conjugation, others in which it has never been seen, and yet others in which it takes place at short intervals without apparent cause.[1]

Depression. In a stock or "culture" of *Paramecium* kept in the laboratory, it often happens that after a time all the members pass into a state of "depression," in which they have an overgrown meganucleus and a

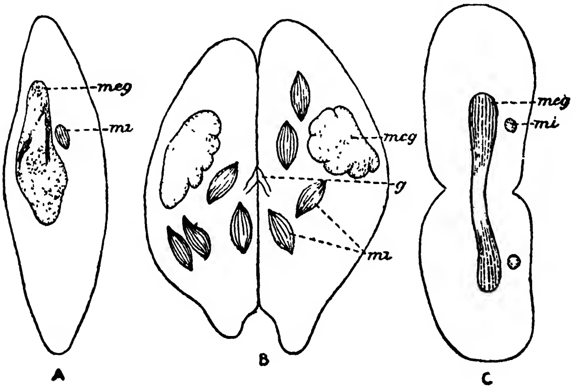


FIG. 84.—Semidiagrammatic views of individuals of *Paramecium caudatum*.

A, In depression; *B*, in conjugation; *C*, in fission.
g., Gullet; *meg.*, meganucleus; *mi.*, micronucleus.

stunted body, divide more slowly, and show an increasing degeneration in various organs and functions of the body. At last they are unable to digest food and die. Depression has been regarded as the old age of the stock and compared with the old age of the individual metazoan, but there are some stocks in which it does not occur, and when it does

[1] It has been said that descendants of the same exconjugant will not conjugate, and that individuals from another stock must be introduced, but this has been disproved.

occur it can be averted, while old age cannot be averted in the metazoan. Depression is an abnormal event, produced by unnatural conditions of culture. In its earlier stages the animals can be stimulated in such a way as to endow them with a new lease of life. This can be done by shaking the culture, or better by a change of diet, as by feeding with beef-tea. After a time the stock can be put back to a diet of hay bacteria and kept till there sets in a deeper depression, which is capable of being averted in the same way. By one means and another (after a while beef-tea failed, and brain and pancreas extracts had to be used) the life of such a culture has been kept up for two years, but the effect of unnatural conditions was in the long run too strong, the recurring periods of depression became more and more severe, and at last the whole brood died.

Vorticella: General Features.

Among the most beautiful forms of pond life are the bell-animalcules, of which the scientific name is *Vorticella*. Various species of these creatures may be found as minute, colourless bodies fastened to weeds by stalks which contract at the slightest disturbance of the water. Some of them also appear in infusions. The body of a *Vorticella* is outwardly shaped like a bell, but has no hollow within, the bell being filled with a mass of protoplasm. In the place of the handle is a long stalk, by which the animal is fastened to some solid object. Animals which are thus fixed are said to be *sessile*. The bell can be bent upon the stalk. The wide end of the bell has a thickened *rim*, within which is a groove known as the *peristome*. On one side there passes from the peristome, down into the mass that fills the bell, a tube known as the gullet. The first part of this is wider than the rest and is sometimes called the vestibule. The part of the upper surface which is encircled by the peristome is known as the *disc*. It is not level, but slopes, being raised on the side where the gullet lies. The disc can be retracted, and the rim of the peristome drawn inward over it. Around the edge of the disc and down into the gullet two rows of cilia wind spirally, the inner row long and standing upright, the outer short and standing outwards. In the gullet the members of the outer row are fused to form an

undulating membrane. There are no cilia elsewhere upon the body.

Ectoplasm and Endoplasm.

The general character of the ectoplasm and endoplasm is the same in *Vorticella* as in *Paramecium*, but the pellicle of the bell-animalcule is sculptured in various ways according to the species, and below it is a distinct alveolar layer. Just under the alveolar layer, in the walls of its bubbles, is a layer of very fine contractile fibres or *myonemes*. Near the stalk the ectoplasm is much thickened and the myonemes pass inwards through it to join in the middle, where they form a central *contractile fibre* which, with a covering of ectoplasm,

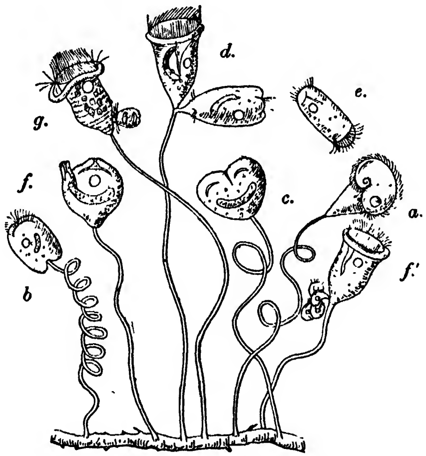


FIG. 85.—A group of individuals of *Vorticella* in various phases of the life-history.

a., Ordinary individual; *b.*, the same contracted; *c.*, ordinary fission; *d.*, a later stage of the same; *e.*, free-swimming individual produced by ordinary fission; *f.*, *f'.*, two modes of fission to form a conjugant; *g.*, conjugation.

makes up the stalk. This is enclosed in a cuticular tube formed by secretion. The contractile fibre is not quite straight, but lies in a very open spiral, so that when it contracts it draws the stalk into a close coil. There are no trichocysts. The endoplasm is granular.

Internal Organs.

A meganucleus and a micronucleus are present, the former a long, curved band, the latter small and placed beside the meganucleus, usually in the upper part of the body. There is a contractile vacuole, which has no canals. It lies in the upper region of the body and communicates with the vestibule through a *reservoir*, which has a narrow permanent opening. The contractile

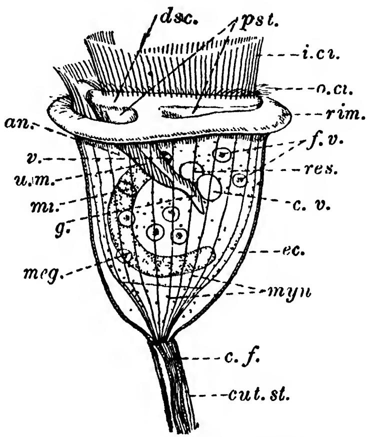


FIG. 86.— *Vorticella*, highly magnified.

an., Position of temporary anus; *c.f.*, contractile filament; *c.v.*, contractile vacuole, *cut.st.*, cuticle of the stalk; *dsc.*, disc; *ec.*, ectoplasm; *f.v.*, food vacuoles; *g.*, gullet; *i.ci.*, inner row of cilia; *meg.*, meganucleus; *mi.*, micronucleus; *myn.*, myonemes; *o.ci.*, outer row of cilia; *pst.*, peristome; *res.*, reservoir of contractile vacuole; *rim*; *u.m.*, undulating membrane; *v.*, vestibule.

vacuole contracts sharply at intervals, discharging into the reservoir. The latter then contracts slowly, driving its contents into the vestibule, but not itself disappearing. Feeding and digestion take place much as in *Paramecium*. The little organisms which serve as food are collected and driven into the gullet by the action of the cilia. The food vacuoles follow a definite, winding course in the body, passing through stages similar to those in *Paramecium*. The fæces

are discharged into the vestibule by an anus, which in some species is a permanent opening through the ectoplasm.

Reproduction. The reproduction of *Vorticella* takes place by binary fission, which is of two kinds—ordinary fission, and that which forms conjugants. In ordinary fission, the rim closes in over the disc, the body becomes shorter and wider, and the meganucleus contracts and lies across the body, which then divides into two, the plane of fission being in line with the stalk. The nuclei behave as in *Paramecium*. One of the daughters remains upon the stalk; the other grows a circlet of cilia in the hinder region, at the level at which the ectoplasm thickens, breaks off, and swims away by means of its cilia, to settle down elsewhere by the end which was attached to the stalk of the parent. It grows a new stalk for itself. In this form of reproduction the offspring are equal in bulk. In the fission which forms conjugants the parent gives rise to one large individual and one or more of a smaller size. The small individuals may arise by unequal binary fission, sometimes called budding, or by equal fission, followed by division of one product into four by repeated fission.[1] In either case the small individuals resemble the free product of ordinary fission in all but size.

Conjugation. The small individuals thus formed swim away, and each attaches itself by its hinder end to the lower part of the body of one of the stalked individuals. Most of the organs of the small individual now disappear, and the ectoplasm between the two conjugants is absorbed into their endoplasm, which becomes continuous. The meganucleus in each begins to break up and disappear. Meanwhile the micronucleus of the small conjugant has divided into two. Now the micronuclei of both conjugants divide twice, so that the larger contains four and the smaller eight micronuclei. In each case all but one of these perish and the survivor divides into two, which correspond to the male and female pronuclei of *Paramecium*. This division takes place while the two micronuclei are

[1] The various kinds of fission of *Amœba*, *Vorticella*, and animals related to them (Protozoa, p. 139) may be classed as: (1) equal binary fission (p. 119), (2) budding (p. 137), (3) repeated fission (p. 124), (4) multiple fission (p. 119).

lying in the region where the endoplasm of the conjugants became continuous. One half of each micronucleus passes into the larger conjugant, where the two fuse as male and female pronuclei. The other half of each passes into the smaller conjugant, but these halves, instead of fusing, degenerate and disappear. The endoplasm of the small exconjugant is now drawn into the larger, the ectoplasm shrivelling up and falling off. It will be seen that the conjugation of *Vorticella* takes place in the same way as that of *Paramecium*, but that one of the two exconjugants perishes and is partly absorbed by the other.[1]

Carchesium. *Carchesium* is a small freshwater animal whose body consists of a number of members, each of which has the structure of a whole *Vorticella*. It arises from a *Vorticella*-like body, by divisions like those which take place in the ordinary reproduction of *Vorticella*, save that the division passes some way down the stem and then stops, leaving the bells joined by their stalks. Thus the body is increased by the addition of new members which repeat the structure of the old. In that it increases the number of energids in the body, this process resembles cell formation, but the two cases differ in that the new energids of *Carchesium* all repeat the whole structure of the first and inherit all its powers, whereas a cell is a portion of the body with peculiar characters and restricted powers. The whole body of a *Carchesium* is said to be a *colony*, and its members are *zooids*. Reproduction is brought about by the complete fission from the body of certain zooids, which thus become asexually produced young or buds. When it has broken off and settled down as an independent individual each of these becomes by division a new colony. Conjugation like that of *Vorticella* also takes place.

Protozoa. The detailed study which we have made of *Paramecium* and *Vorticella* has shown to what an extent organisation can be carried without the division of the body into cells. Ranging in grade of organisation

[1] The student should beware of comparing the smaller conjugant of *Vorticella* with a spermatozoon and the larger with an ovum. Ova and spermatozoa are gametes of unlike kinds. The conjugants of *Vorticella* are unlike, hermaphrodite parents, each of which forms two unlike gametes.

CHAPTER IX

HYDRA

Hydra: General Features.

IF a handful of weeds gathered from a freshwater pond be placed in a beaker of water and allowed to stand for a while, there will often be found hanging from the sides of the beaker or from the weeds some short threads of a green, brown, or whitish colour. By one end each thread cleaves to the glass. At the other it bears about half a dozen finer threads, which hang down in the water if they be left undisturbed. A touch will cause these to be withdrawn and take on a shorter and thicker shape, interference with the thread from which they hang is followed by a similar change, and in this way the whole can be made to contract into a vase-shaped mass surmounted by a circlet of little knobs. From time to time water-fleas and other small animals swim against the fine threads and may be seen either to drop through the water as though they were stunned, but afterwards to recover and swim away, or else to remain sticking to the fine threads, which shorten and draw the animal towards the end of the main thread, into which they are swallowed. It is clear that these objects are living beings: in point of fact each of them is a specimen of the animal known as *Hydra*. According to their colour they have been named *H. viridis*, *H. fusca*, and *H. grisea*. The three kinds differ slightly in other respects besides colour, but the following account applies to all of them.

Shape.

The body of *Hydra* is a hollow cylinder, with a ring of hollow outgrowths or *tentacles* surrounding an opening or mouth at one end, and the other end closed by a flat *basal disc or foot*. The mouth is raised

upon an *oral cone or hypostome*; it leads into the hollow of the cylinder, with which the hollows of the tentacles are continuous. This space is the *enteron*. The cylinder is rather wider in the middle than near the ends. The wall of the body is composed of two protoplasmic layers, the outer known as the *ectoderm* and the inner as the *endoderm*, with a *structureless lamella or mesoglea* between them, consisting of a gelatinous substance which they secrete. Such a body as this is known as a *polyp*.

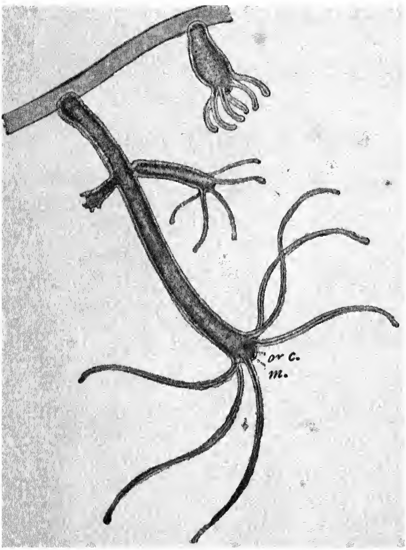


FIG. 95.—Two specimens of *Hydra* magnified, one contracted, the other in a state of moderate expansion, the latter bearing two buds in different stages.

m., Mouth; *or.c.*, oral cone.

Ectoderm. The ectoderm consists of several kinds of cells, of which the most conspicuous are those known as *musculo-epithelial cells*. These are roughly conical in shape, with their broad ends directed outwards and fused to form a continuous layer of protoplasm over the body. The apex of the cone is drawn out into one or more *contractile processes*, which run along the cylinder and tentacles, at right angles to the main part of the cell, forming a distinct layer on the outer side of the structureless lamella. Over the greater part of the body the surface layer of the protoplasm is a firm pellicle, but in the disc this is absent. The cells in this region are also peculiar in containing granules of a substance secreted by the protoplasm which is used to fix the

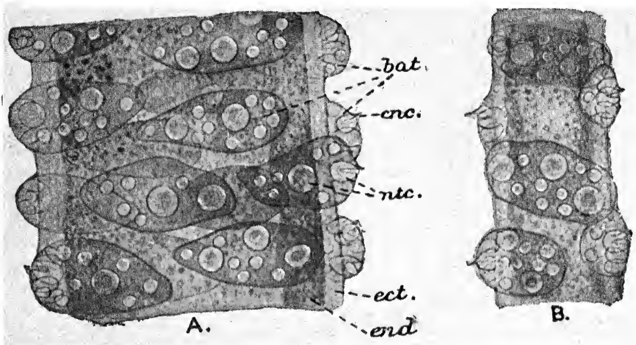


FIG. 97.—Portions of tentacles of *Hydra* magnified.

A, Moderately contracted; *B*, Moderately extended.

bat., Batteries; *cnc.*, cnidocil; *ect.*, ectoderm; *end.*, endoderm; *ntc.*, nematocysts.
Some of the batteries, and parts of others, are seen through the thickness of the tentacle.

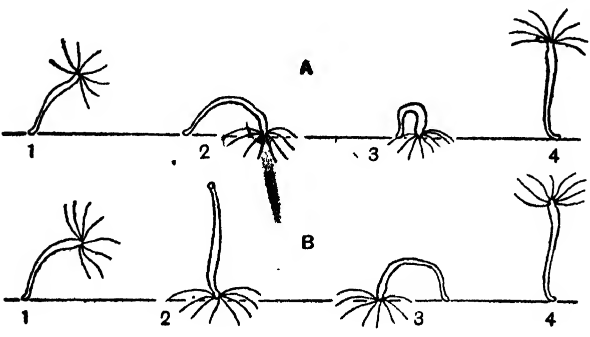


FIG. 98.—Hydra in the attitudes which it assumes successively in two of its modes of locomotion (p. 158).

A, "Looping"; *B*, "somersaulting."

produced into a long, hollow thread, which lies coiled up in the sac. The space between the thread and the wall of the sac contains a fluid, and there is a specially contractile layer of protoplasm around the sac. The cnidocil is a sense organ. When it is stimulated the contractile layer squeezes the sac, and the pressure upon the contained fluid expels the thread, turning it inside out.[1] The nematocysts are of three kinds—a large kind with a straight thread provided with barbs at the base, a small kind with a spiral thread, and a second small kind with a straight thread and a narrower sac than the others. Neither of the small kinds has barbs. The broad end of each cnidoblast is anchored into the body by a process which runs inward towards the structureless lamella. The tentacles are covered with a number of warts, each consisting of a large musculo-epithelial cell, in which is sunk a battery of cnidoblasts consisting of one or two of the large kind with several of the smaller kinds around them. Each of the kinds of nematocysts has a function of its own. Those of the large, barbed variety are weapons of offence and perhaps also of defence. Their cnidocils are affected by chemical stimuli afforded by the substances given off from the bodies of other animals. When the nematocysts are discharged, their barbs emerge first and make a wound in the tissues of the prey, into which the thread is driven. In piercing the horny skin of the water-fleas, upon which the *Hydra* principally feeds, they are assisted by the corrosive action of a fluid which they contain, either in the hollow of the tucked-in

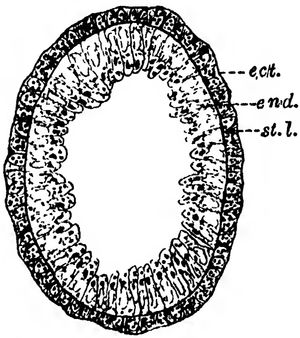


FIG. 99.—A transverse section of *Hydra*, stained and seen under the low power of the microscope.

ect., Ectoderm; *end.*, endoderm; *st.l.*, structureless lamella.

[1] It is maintained by some authorities that the thread is expelled not by a contractile layer of protoplasm, but by the swelling up of a jelly which (and not a fluid) they believe the nematocyst to contain.

thread or in that of the sac. This fluid has also a temporary numbing action upon the prey, but the main

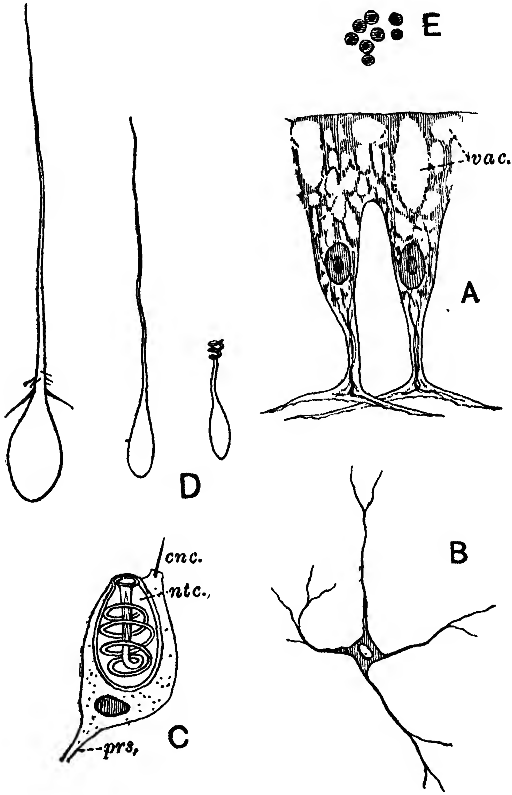


FIG. 100.—The histology of *Hydra*.

A, Two musculo-epithelial cells; *B*, a nerve cell; *C*, a cnidoblast; *D*, nematocysts of three kinds; *E*, Zoochlorellæ.

cnc., Cnidocil; *ntc.*, nematocyst; *prs.*, basal process of the cnidoblast; *vac.*, vacuoles in musculo-epithelial cells.

purpose of the nematocysts is not to kill but to hold the prey until it is swallowed. In this the spiral nematocysts

assist by coiling round bristles upon the body of the prey. The third kind of nematocysts is of use in attaching the tentacles of the animal, either to its prey or to other objects when necessary, by the stickiness of their threads. The cnidoblasts arise from the interstitial cells by the formation of a vacuole and its gradual modification into a nematocyst. They are formed in the upper region of the cylinder and migrate thence to various parts of the body, where they take up their position in the outer layer. The *germ cells* also arise in the ectoderm from the interstitial cells by a process which we shall describe later. Lastly, the ectoderm contains, in the region where the interstitial cells lie, a mesh-work of branching *nerve cells* which are said to be connected with tall, narrow *sense cells* that reach between the musculo-epithelial cells to the surface. Thus *Hydra* possesses a nervous system, but this is in the most rudimentary condition possible, consisting of a continuous subepithelial plexus of conducting cells without a central nervous system, while the cell bodies from which the afferent fibres arise are placed among the cells which cover a surface, as in the olfactory epithelium of the frog, not removed from it like those of most of the afferent fibres in the latter animal (Fig. 51).

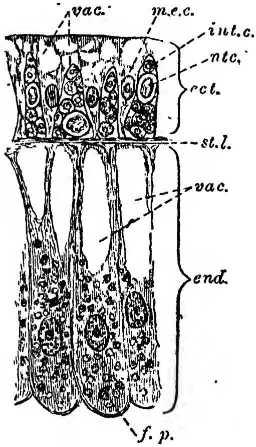


FIG. 101.—A small portion of a transverse section of *Hydra*.

ect., Ectoderm. *end.*, endoderm; *f.p.*, food particle, ingested by an endoderm cell; *int.c.*, interstitial cells; *m.e.c.*, musculo-epithelial cell; *ntc.*, nematocyst; *st.l.*, structureless lamella; *vac.*, vacuoles in endoderm cells; *vac'.*, vacuoles in ectoderm cells.

Endoderm. In the endoderm the cells are all tall and columnar. Certain of them, especially numerous in the oral cone and absent from the tentacles, are *glandular*. They have a narrow stem and a wide end, turned towards the enteron and containing granules of a

substance which they secrete. The most numerous and conspicuous cells are *nutritive.* They are columnar, and have their bases produced into contractile fibres, which are shorter than those of the musculo-epithelial cells and run around the body, not along it. Their protoplasm contains large vacuoles, and also, in the green *Hydra*, a number of round bodies of a green colour, each of which consists of a central mass of protoplasm with a covering of a different kind of protoplasm containing the green substance known as *chlorophyll* to which the colour of plants is due. These bodies multiply by division. In the brown *Hydra* the green bodies are absent, but there are present some yellowish bodies of similar shape, in which, however, no structure can be made out. It is said that these are also present in the green *Hydra.* The ends of the cells which abut on the enteron bear flagella, which can be withdrawn and replaced by pseudopodia.

The green bodies of *Hydra viridis* have been shown to be individuals of a minute plant known as *Zoochlorella*, which have simple and degenerate structure. Like other plants, they nourish themselves in a manner radically different from that of animals. This they do by means of the chlorophyll. Absorbing certain rays of light, that substance enables the protoplasm, in some way not yet understood, to use the energy of such rays in breaking up molecules of carbon dioxide taken in from the surroundings, which in the case of land plants is the air, in water plants is the water, and in the green bodies of *Hydra* is the protoplasm of the animal. The carbon thus obtained is combined with the hydrogen and oxygen of water also absorbed, to form sugar.[1] The oxygen of the carbon dioxide is set free. This can easily be shown in the case of water plants, from whose leaves in sunlight a stream of fine bubbles of oxygen may be seen to ascend. It has been shown that oxygen is also given off from the body of the green *Hydra.* The sugar is used on the one hand for the manufacture of the carbohydrates, in which the plant body is usually very rich, and on the other hand for the formation of the various substances which the protoplasm of plants, like that of animals, requires for food, and in particular of proteins.

[1] The substance first formed is Formaldehyde, H.COH.

The nitrogen, sulphur, and phosphorus for this purpose are obtained by most plants as salts in solution in the water they take in, by their roots or sometimes by the whole surface of the body. The green bodies of *Hydra* obtain these elements in certain waste products of the metabolism of the animal which they absorb. It may be that the *Hydra* absorbs from them in return the excess of carbohydrates which they form; and this would account for the absence from them of starch, which is so constantly found in plants. Thus there is between the two organisms a partnership, in which the animal benefits by the removal of waste products and the supply of oxygen and possibly of carbohydrates, and the plant benefits by the rich supply of nitrogenous material and carbon dioxide. Such a partnership is known as *symbiosis* and is in strong contrast with parasitism, in which one of the partners benefits at the expense of the other. *Hydra*, *Zoochlorella*, and the fungi are examples of the three kinds of nutrition found among living beings. While the food of animals, which consists of complex organic substances, is usually in the state of a solid or of the viscous liquid of protoplasm, and has to be swallowed through an opening, the materials taken in by green plants are simple inorganic substances which can be absorbed as gases or liquids through the surface of the body. Plants which have no chlorophyll, such as fungi, and some animals which live as parasites or in decaying matter, absorb their nourishment through the surface of the body, but take it in the form of organic substances, more or less complex in various cases, derived from the bodies of other organisms. Thus there can be distinguished three kinds of nutrition: (1) *holozoic*, in which the food is organic and is swallowed; (2) *holophytic*, in which the food is inorganic and is absorbed through the outer surface; (3) *saprophytic*, in which the food is organic and is absorbed.[1] It must, however, be understood clearly that these differences concern only the form and manner in which food enters the body. The food which is incor-

[1] The modes of nutrition classed under the general title "saprophytic" vary greatly in detail, ranging from cases in which the food substances are not much more complex than that of a plant, save that sugar is substituted for carbon dioxide, to cases which differ from holozoic nutrition only in the way in which the food enters the body.

porated by the protoplasm always contains complex organic substances.

Movements and Reactions.

The movements of *Hydra* are carried out mainly by the muscular processes of the cells, though the surface of the basal disc can put forth pseudopodia, and it is possible that by means of these the animal can slowly change its position. The muscular processes of the ectoderm cells, when they contract, make the body shorter and wider; those of the endoderm make it narrower and longer. The position of rest is one of moderate extension. *Hydra* does not remain passive in the absence of stimuli, but, after standing for some time extended in readiness for prey, it automatically contracts either the whole body or the tentacles only, and then extends in a new direction. Thus it explores the whole of its surroundings. From time to time it changes its position. This is done by extending the body and bending it, so that the tentacles touch some neighbouring object and adhere to it by means of the nematocysts with sticky threads. The basal disc is then either withdrawn altogether from the spot to which it was fixed and put down in a new spot close to the tentacles, or caused to glide up to the tentacles. In either case the animal moves in somewhat the same way as a looper caterpillar. A *Hydra* responds to every stimulus, except that of food, by contraction. If the stimulus be weak it affects only the part of the body to which it is applied, as a single tentacle will withdraw from a slight touch; if it be strong its effect spreads to the whole body. A stimulus applied to one side of the body a number of times causes it presently to move away in some other direction. *Hydra* avoids both too feeble and too strong a light.

Nutrition and Excretion.

The food of *Hydra* consists of water-fleas and other small animals. These are caught by the tentacles, and carried by them to the mouth, which then opens and swallows the prey. The animal will not feed unless it be hungry. If it be well fed, creatures which swim against the tentacles are allowed to escape, but, if food has been scarce, as soon as the prey has become temporarily attached by the nematocysts to one tentacle the others bend over towards it and help to secure it and push it towards the mouth. If the

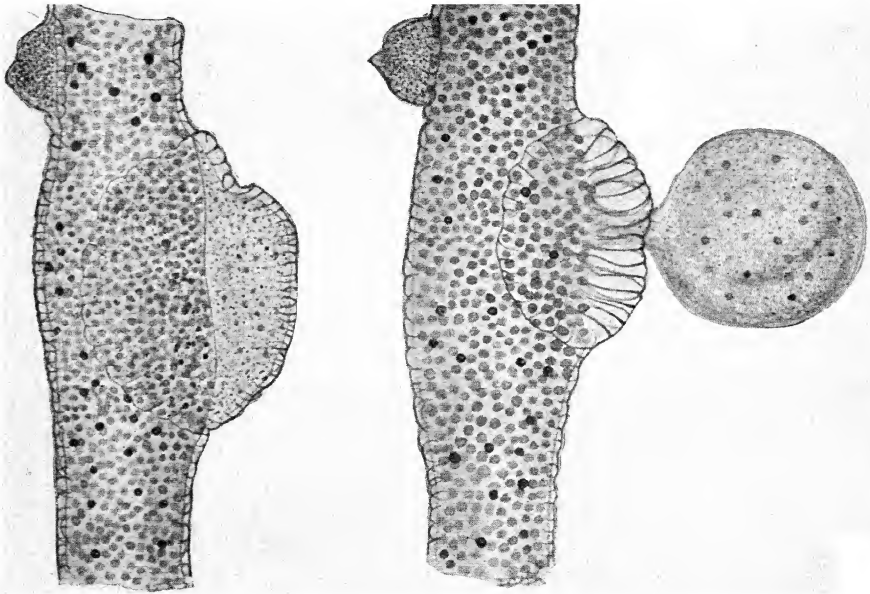


PLATE III.—Reproductive organs of the green *Hydra*.

In each case a testis is shown above, to the left, and an ovary below, to the right. In *A* the ovum is unripe, in *B* it is ripe, has burst its covering of ectoderm cells, and hangs by a stalk. The large round spots in the ovum are *Zoochlorellæ*.

animal be starving the mere smell of food in the neighbourhood is enough to set the tentacles working, but usually they are not put into action till the food has been both smelt and touched. It is not possible to deceive the *Hydra* into swallowing substances, such as pieces of blotting-paper, which do not smell like food, but blotting-paper soaked in beef-tea is swallowed when it touches the tentacles. Once swallowed, the food is passed deep into the enteron and there softened by a juice which the endoderm secretes (from the gland cells already mentioned) and broken up by the churning which it gets as the body expands and contracts. Part of the food is dissolved in the enteron and absorbed in solution, part of it is taken up by pseudopodia of the endoderm cells and digested within their protoplasm. Presumably the ectoderm is nourished by substances passed on from the endoderm, either by diffusion through the structureless lamella or along the fine threads of protoplasm which put the two layers into connection across it. The undigested remains of the food are driven out of the mouth by a sudden contraction of the wall of the body. In unnatural conditions of culture the animals become liable to depression much like that of *Paramecium*, in which the powers of movement, feeding, and fission are affected and death ensues. *Respiration* and *excretion* probably take place from the surface of the ectoderm and endoderm; there is no special organ for either process.

Reproduction. The species of *Hydra* reproduce themselves both sexually and asexually. The sexual reproduction of *H. viridis* and *H. grisea* takes place normally in the spring and summer, that of *H. fusca* in the autumn. The animals are usually hermaphrodite, but strains are met with in which the sexes are separate. The generative organs are ectodermal structures developed when sexual reproduction is about to take place. The ovaries, of which there is generally only one in each individual, are found in the lower part of the body; the testes, of which there are several, are in the upper part. In the early stages of both organs the interstitial cells multiply and push out the musculo-epithelial cells so as to form a swelling. In the case of the ovary one of the interstitial cells becomes an oocyte (p. 107). This increases in size and begins to throw out

pseudopodia, by which it swallows the rest of the interstitial cells contained in the swelling. At the same time it lays up in its protoplasm numerous dark, spherical granules of yolk. As the swelling increases, the musculo-epithelial cells are stretched, their conical bodies forming long stalks, which are pushed apart by the oocyte, and their outer layer forming a thin covering for the latter. When the oocyte has swallowed all the surrounding cells it withdraws its pseudopodia and becomes a large rounded body, about which a gelatinous coat is secreted. Polar bodies are now formed, the covering of musculo-epithelial cells parts and shrinks back so that the ovum is exposed save for the gelatinous coat, and fertilisation is effected by one of the spermatozoa which are present in the surrounding water. In the formation of a testis the multiplication of the interstitial cells stretches the musculo-epithelial cells as in the ovary. The interstitial cells become spermatocytes, which lie among the stalks of the musculo-epithelial cells and undergo two divisions as in the frog, the resulting cells developing into spermatozoa with a conical head, a neck, and a tail. By the breaking of the covering layer the spermatozoa are set free and swim in the water, where they perish unless they find a ripe ovum. Since either the ovary or the testis generally ripens first, cross-fertilisation will usually take place, but it does not appear that self-fertilisation is always impossible.

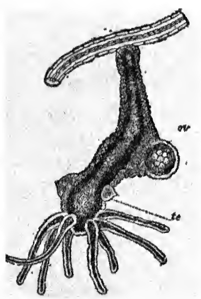


FIG. 102.—*Hydra* hanging from water-weed.

ov., Ovary, with nearly ripe ovum; *te.*, testes.
See also Plate XVI.

Development. After fertilisation the oosperm undergoes cleavage into blastomeres (p. 110), which as they increase in numbers form at first a hollow sphere known as the *blastula*, whose wall consists of a single layer of cells. Some of these migrate into the hollow, which they fill. The outer layer now represents ectoderm and the inner mass endoderm. The cells of the ectoderm become smaller than those of the endoderm and lose their yolk granules. A thick, spiny covering of a horny substance is now secreted by the ectoderm, and the round, prickly body thus formed falls away from the parent and rests for several weeks, during which it may be carried about by currents, in

mud on the feet of water animals, etc. After a time the ectoderm differentiates into musculo-epithelial and interstitial cells, the jelly is secreted, the shell cracks, and the embryo projects. A split in the endoderm forms the enteron, tentacles grow out, a mouth is formed, and finally the young *Hydra* frees itself from the remains of the shell, moves away, and begins to feed and grow.

Asexual reproduction also begins with the formation of a swelling of ectoderm by the multiplication of the interstitial

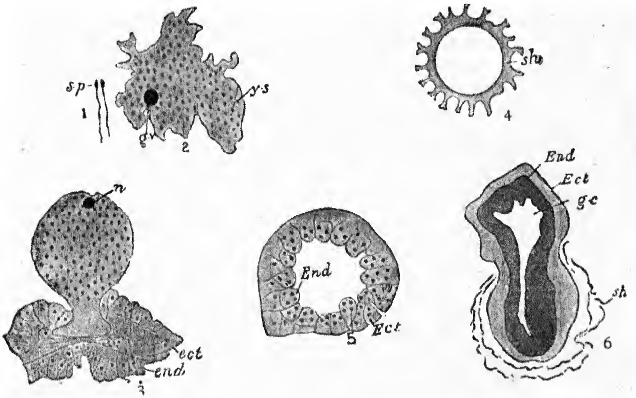


FIG. 103.—The development of *Hydra*.—After Brauer.

1. *sp.*, Spermatozoa.
2. Amœboid ovum; *g.v.*, germinal vesicle or nucleus; *y.s.*, yolk spherules.
3. Ovum protruding; *n.*, the nucleus; *ect.*, the ruptured ectoderm of the parent; *end.*, the endoderm.
4. Ovum with prickly envelope (*sh.*) around it.
5. Section of blastosphere—*Ect.*, ectoderm; *End.*, endoderm—being formed.
6. Section of larva. *Ect.*, ectoderm; *End.*, endoderm; *g.c.*, enteron; *sh.*, ruptured envelopes.

cells, which afterwards become converted into musculo-epithelial and endoderm cells, passing through the structureless lamella in the latter case. The result of this is an increase in the extent of the ectoderm and endoderm which leads to a bulging of the body-wall. The knob or *bud* thus formed becomes longer, tentacles grow out around its free end, a mouth is formed, and finally the base narrows till the bud breaks free as a new individual, which grows till it reaches the size of the parent. The buds arise in the middle of the

body of the parent. Several may be formed at the same time, and a bud may form secondary buds before it is set free. While it is still on the parent, the bud is wholly a part of the body of the latter. Each of the layers of the parent is continuous with the corresponding layer of the bud, a suitable stimulus is transmitted by the nervous system from one to the other, and the entera are in free communication, so that food obtained by either is available for the other. Occasionally a *Hydra* will reproduce by fission into two, either lengthwise or transversely, of the whole body. In this case, as in the fission of a *Paramecium*, structural development as well as the growth of each product of fission must take place after separation, whereas in the bud, as we have seen, the structural development takes place before fission.

Regeneration. A property akin to asexual reproduction is that of *regeneration* or the replacement of lost parts, which is possessed by *Hydra* in a very high degree. To some extent all organisms have this power, but as a rule the higher the animal the less is its faculty for regeneration. In man it is little more than the power of healing wounds. Not only will *Hydra* grow anew any part, such as a tentacle, which is cut off, but any fragment of the body, provided it be not too small and contain portions of both layers, will grow into an entire animal.

CHAPTER X

THE EARTHWORM. ANNELIDA

Habits.

ALMOST everywhere in England earthworms are found. They live usually in the upper layers of the soil in burrows, which they make partly by boring with the pointed front ends of their bodies, partly by swallowing the earth in front and passing it out behind, in which case the earth which is passed out forms the well-known "worm casts." The sides of the burrow are lined with a slime secreted by unicellular glands in the skin, and if the opening be not protected by a worm cast it is usually

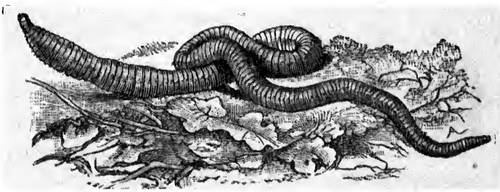


FIG. 104.—The Earthworm.—From Thomson.

closed by leaves or small stones. Such leaves may often be seen sticking up from the ground, and will be found to have been pulled into the burrow skilfully, with the narrowest part foremost. At night, if the weather be warm and not too dry, the worms will stretch themselves out of their holes, keeping the hinder end of the body fixed in the opening, so that they can pull themselves back at once if danger threatens. In dry weather or hard frost they burrow deep and retire to a small chamber, which they line with little stones. In wet weather they are sometimes flooded

out, but they rarely leave their burrows in other circumstances, except when they are about to die owing to the attacks of parasitic maggots which are the young of certain flies. The food of earthworms consists of the organic matter in the soil, which they swallow, and of leaves both fresh and decaying. They will also eat animal matter, and are said to be very fond of fat. Charles Darwin has shown the remarkable effects which these insignificant creatures have upon the surface of the earth. By making the soil more porous they expose the underlying rocks to the disintegrating action of water, by solution owing to the presence of carbon dioxide and other acids of the soil, and by frost, and the small stones which eventually result from this action are made still smaller by friction and solution within their bodies. Thus they help in the formation of the soil. At the same time they are aiding in its removal. Their castings dry and crumble, and are blown about by the wind or else are washed down by the rain. On sloping ground this fine material tends to be carried away downwards, and thus the denudation of hills is largely due to the action of earthworms. On the other hand, their work is highly beneficial to the farmer. The soil is by them thoroughly mixed, submitted to the action of the air, and constantly supplied with a fine "top dressing." It has been calculated that earthworms bring up annually a layer of soil one-fifth of an inch in thickness, which is spread by the weather in the way we have described. Organic matter is converted into a useful form and amalgamated with the earth, and the latter is made easier of penetration by the roots of plants.

The commonest English earthworm is *Lumbricus herculeus*.

External Features.

The body of this animal is roughly cylindrical, but pointed in front and broadened behind. It reaches a length of seven inches. There is no distinct head, but a lobe known as the *prostomium* overhangs the mouth, which is a crescentic opening on the lower side of the front end. The body is divided into a series of rings or *segments*, and at the hinder end is the terminal *anus*. The first segment is known as the *peristomium* and the mouth lies between it and the prostomium. On the dorsal side, the latter projects across

the peristomium.[1] There are about 150 segments. At about one-third of the length of the body from its front end, in segments 32–37 inclusive, a glandular thickening of the epidermis lies athwart the back like a saddle and is often mistaken for the scar of a wound. This is known as the *clitellum.* The skin of the worm is brownish above and paler below; it is covered with a fine, tough, iridescent cuticle secreted by the underlying cells. In every segment except the first and the last there are eight bristles or *setæ*, placed in two pairs on each side, a *lateral pair*, slightly above the middle of the side, and a *ventral pair* between the lateral and the mid-ventral line. The setæ can be felt with the fingers; they are embedded in sacs of the epidermis, by which they are secreted, and to these sacs are attached muscles, by which they can be moved. The setæ are organs of locomotion. The worm extends its body with the bristles withdrawn. Then it thrusts out those of the forepart, so that they catch in the soil and hold firm while

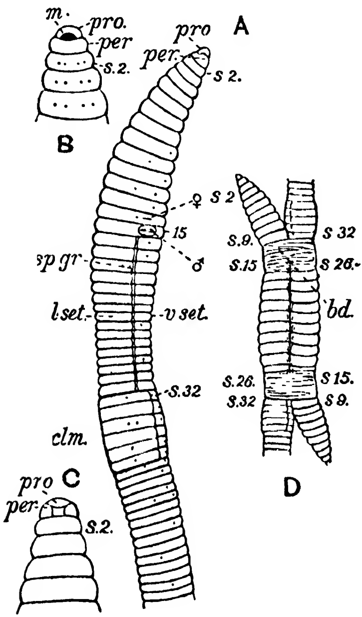


FIG. 105.—*A*, The forepart of the body of an earthworm (*Lumbricus herculeus*), from the right side; *B*, the first five segments from below; *C*, the same from above; *D*, worms in coition.

bd., Band of mucus; *clm.*, clitellum; *l.set.*, lateral setæ; *m.*, mouth; *per.*, peristomium; *pro.*, prostomium; *s.*2, *s.*9, *s.*15, *s.*26, *s.*32, numbers of segments; *sp.gr.*, spermatic groove; *v.set.*, ventral setæ; ♂, opening of vas deferens; ♀, opening of oviduct.

[1] In the related *Allolobophora* the prostomium reaches only half-way across the peristomium.

the hinder region is being drawn up. A wave of movement of this kind passes down the body. The ventral setæ of the clitellum, of the twenty-sixth, and of the tenth to the fifteenth segments are straighter and more slender than those of other segments, which are stout and somewhat hooked. This modification is in connection with the use of the setæ of the twenty-sixth segment during coition, and of the other straight setæ during the formation of the cocoon in which the eggs are laid.

External Openings.

A number of internal organs open separately upon the surface of the body. We have already mentioned the mouth and anus. The *openings of the vasa deferentia* are a pair of slits with swollen lips found on the under side of the body in segment 15. In front of them, in segment 14, are the two small *openings of the oviducts.* The *spermathecal pores* are two pairs of small, round openings in the grooves between segments 9–10 and 10–11 at the level of the lateral setæ. The *nephridiopores* are openings which lead from the excretory tubes or nephridia. They are found, as a pair of minute pores in front of the ventral setæ, in each segment except the first three and the last. The *dorsal pores* are small, round openings on the mid-dorsal line in the grooves between the segments. The first is behind the eighth segment, and there is one in each subsequent groove. They open into the body cavity, the fluid in which oozes out through them and moistens the surface of the body, mingling with the slime secreted by the unicellular glands of the skin. As this fluid contains amœboid cells which attack bacteria and other small parasites, it is a valuable defence to the worm against such enemies, which are numerous in the soil.

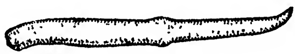


FIG. 106.—One of the ordinary setæ of an earthworm, removed from the seta sac and magnified.

Body-wall.

The body of the worm may be said to consist of two tubes, one within the other. The inner tube is the gut, the outer the body-wall. Between the two lies the cœlom or body cavity, divided into compartments by a series of *septa*, which reach from the gut to the

body-wall, where they are attached opposite the grooves on the surface of the body. The cœlom contains a fluid, and in this float the leucocytes already mentioned, by which small parasites are surrounded and destroyed, both within

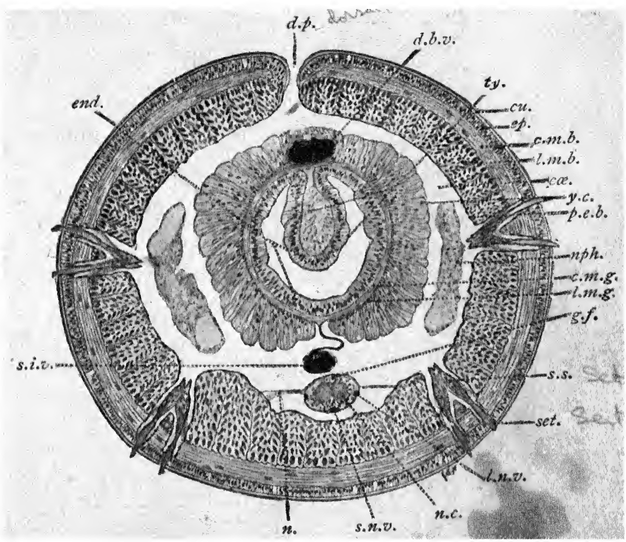


FIG. 107.—A transverse section through an earthworm in the region of the intestine.

cæ., Cœlom ; *c.m.b.*, circular muscle of body-wall ; *c.m.g.*, circular muscle of gut ; *c.u.*, cuticle ; *d.b.v.*, dorsal blood vessel ; *d.p.*, dorsal pore ; *ep.*, epidermis ; *end.*, endoderm ; *g.f.*, giant fibres ; *l.m.b.*, longitudinal muscle of body-wall ; *l.m.g.*, longitudinal muscle of gut ; *l.n.v.*, lateral neural vessel ; *n.*, nerves ; *n.c.*, nerve cord ; *nph.*, nephridium ; *p.e.b.*, peritoneal epithelium of body-wall ; *set.*, seta ; *s.i.v.*, subintestinal blood vessel ; *s.n.v.*, subneural blood vessel ; *s.s.*, seta sac ; *ty.*, typhlosole ; *y.c.*, yellow cells. Seta sac muscles are shown but not lettered.

Some of the structures seen in this section are shown more highly magnified in Fig. 110

and without the body. The *body-wall* is covered by the *cuticle*. Under this lies the *epidermis*, an epithelium consisting of columnar cells, many of which are glandular or sensory, with small cells between their bases. The cuticle is perforated by a pore over each gland cell. The epidermis of the clitellum consists of several layers of gland

cells. Below the epidermis is a *circular layer of muscle*, consisting of unstriped fibres running around the body, and below this again lies a much thicker *longitudinal layer of muscle*, composed of similar fibres running along the body and placed in rows which stand at right angles to the surface, supported by connective tissue. Within the longitudinal muscle is the cœlomic epithelium, which is here a layer of pavement cells lining the body cavity.

Gut. The alimentary canal is straight. It begins with a short, wide, thin-walled mouth or buccal cavity in the first three segments which leads to a muscular region known as the pharynx. This lies in front of the septum between the fifth

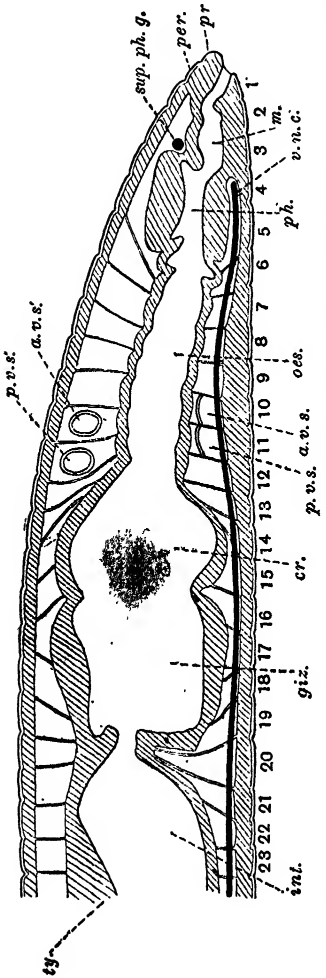


FIG. 108.—A diagram of a longitudinal section of an earthworm.

a.v.s. Anterior vesicula seminalis.
a.v.s'. Posterior lateral horn of the same overhanging the œsophagus.
cr. Crop.
giz. Gizzard.
int. Intestine.
m. Mouth.
œs. Œsophagus.
p v.s. Posterior vesicula seminalis.
p.v.s'. Horn of the same overhanging the œsophagus.
per. Peristomium.
ph. Pharynx.
pr. Prostomium.
sup.ph.g. Suprapharyngeal ganglion.
ty. Typhlosole.
v.n.c. Ventral nerve cord.
1–23. Segments.

The blood vessels are omitted.

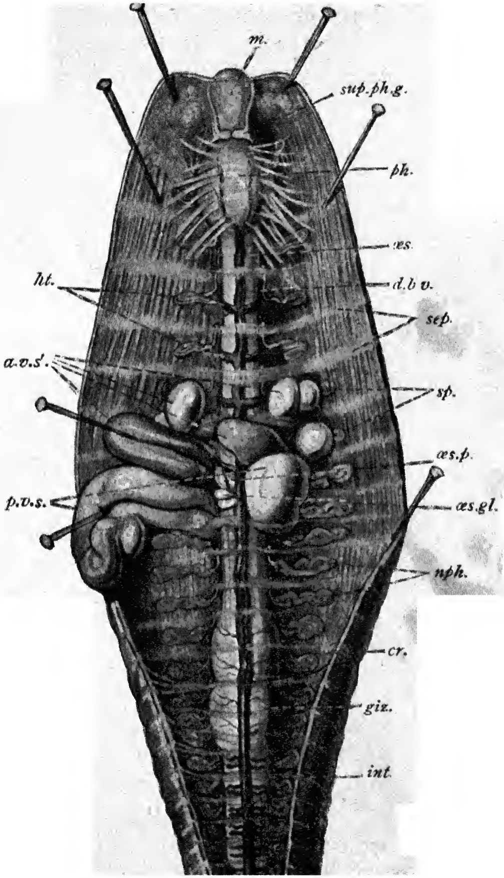


FIG. 109 —An earthworm (*L. herculeus*), dissected from above.

a.v.s'., Horns of the anterior vesicula seminalis; *cr.*, crop; *d.b.v.*, dorsal blood vessel; *giz.*, gizzard; *ht.*, hearts; *int.*, intestine; *m.*, mouth; *nph.*, nephridia; *œs.*, œsophagus; *œs.gl.*, œsophageal glands; *œs.p.*, œsophageal pouch; *p.v.s'.*, horns of the posterior vesicula seminalis; *ph.*, pharynx; *sep.*, septa, *sp.*, spermathecæ; *sup.ph.g.*, suprapharyngeal ganglia.

and sixth segments, but pushes the latter backwards ·*cle*, as the seventh. Its dorsal wall is thickened by the pre‹nd

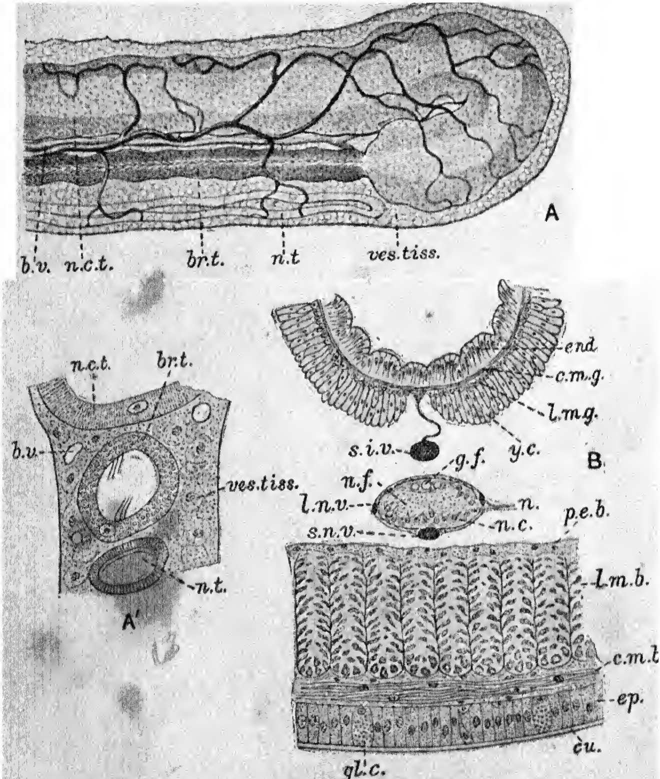


FIG. 110 —Histology of the earthworm.

A, The end of the first hank of the nephridium (Fig. 114); *A'*, part of a section of the same; *B*, part of a transverse section of the body.

b.v., Blood vessel; *gl.c.*, gland cell in the epidermis. Other letters as in Fig. 114 (*A* and *A'*) and Fig. 107 (*B*).

of a number of glands, whose secretion, containing mucin and a ferment which digests protein, is poured over vegetable tissues while the animal is feeding upon them. Numerous strands of muscle run from it to the body-wall.

Behind it lies the œsophagus, a straight, narrow, thin-walled tube, which extends to the fourteenth segment. In the eleventh segment it bears at the sides a pair of *œsophageal pouches*, and in the twelfth two pairs of *œsophageal glands*. These contain large cells which secrete calcium carbonate and pass it through the pouches into the œsophagus. In the fifteenth and sixteenth segments the œsophagus expands into a large, thin-walled *crop*, which in turn communicates behind with the *gizzard*, another swelling, with thick muscular walls and a horny lining, in segments 17 and 18. From the gizzard to the anus runs a wide, thin-walled tube known as the intestine. The intestine is narrowed where it passes through the septa, and its dorsal wall is infolded to form a longitudinal ridge known as the *typhlosole*. The gut is lined with a layer of columnar epithelium, outside which are thin longitudinal and circular muscular layers, covered by the cœlomic epithelium, which here consists of the *yellow or chloragogenous cells*. These are large and contain yellow granules of an excretory product. They fall off into the cœlomic fluid, and there break up and set free their granules which are said to be taken up by some of the amœboid cells and in them expelled through the dorsal pores. The typhlosole is filled with yellow cells.

Food is drawn into the mouth by a sucking action of the muscular pharynx, passed along the œsophagus, stored in the crop, ground up in the gizzard with the aid of small stones which have been swallowed, and in the intestine first digested by juices secreted from the epithelium, and then absorbed. The surface for these purposes is increased by the presence of the typhlosole. The function of the secretion of the œsophageal glands is uncertain. It has been supposed to be an excretion of the calcareous matter, which is very plentiful in the dead leaves, of which the food is largely composed. Probably it has some further function, whether this be the neutralisation of the acids of the food, or, as seems to be the case, the removal of carbon dioxide in the form of calcium carbonate.

The earthworm has a well-developed central nervous system which consists of (1) a pair of *suprapharyngeal ganglia*, rounded bodies lying above the mouth, and

Nervous System.

sometimes known together as the *brain*, (2) two slender *circumpharyngeal commissures* running from these round the pharynx, and (3) a *ventral nerve cord* which starts from the commissures between the third and fourth segments and runs the whole length of the body in the cœlom below the gut, swelling into a ganglion in each segment. The first of these ganglia is bilobed and is known as the *subpharyngeal ganglion*. Nerves are given off to the prostomium from the supra-pharyngeal ganglia, and to the first two segments from the commissures, and the ventral cord gives off three pairs of nerves in each segment. The forepart of the alimentary canal receives nerves from the circumpharyngeal commissures. Though the ventral cord appears to be single, it is really double, and can be seen in transverse sections to be divided into right and left halves by connective tissue. Transverse sections also show that the middle and upper part of the cord consists of fine longitudinal nerve fibres and the lower and outer parts of nerve cells. Above the mass of fine longitudinal fibres are three bundles of such fibres, each bundle being enclosed in a sheath and known as a *giant fibre*. The nerves consist of afferent fibres, which start in sense cells of the epidermis and end as a bunch of fibrils in the central nervous system, and efferent fibres, which start from nerve cells in the ganglia and end against muscle and other cells.

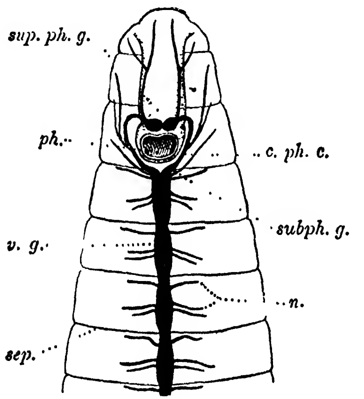


FIG. 111.—A diagram of the forepart of the nervous system of the earthworm.

c.ph.c., Circumpharyngeal commissure; *n.*, nerves; *ph.*, pharynx cut through; *sep.*, septa; *subph.g.*, subpharyngeal ganglia; *sup.ph.g.*, suprapharyngeal ganglia; *v.g.*, ganglia of ventral cord.

An earthworm has no well-developed organs of sense, but certain of the columnar cells of the epidermis are rod-shaped

and prolonged at their inner ends into fibres, which run in the nervous system (Fig. 112). These are sense cells, and in the forepart of the body some of them are collected into groups, which are rudimentary sense organs. Experiment shows that the worms are sensitive to light and to vibrations of the ground and can smell, but gives no evidence of a sense of hearing.

Sense Organs.

Excretion.

B sides the yellow cells, the earthworm has excretory organs which, lik those of the frog, consist of tubes with walls that are glandular and excretory and richly supplied with blood vessels, but the tubes, inst ad of being col-lect.d into compact kidneys, are distributed along the body, one pair to each segment, except the first three and the la t. Each tube or *nephridium* is thrown into loops, bound together by connective tissue containing blood vessels. The nephridium begins as a kidney-shaped funnel or *nephrostome* hanging from the front side of a septum near the

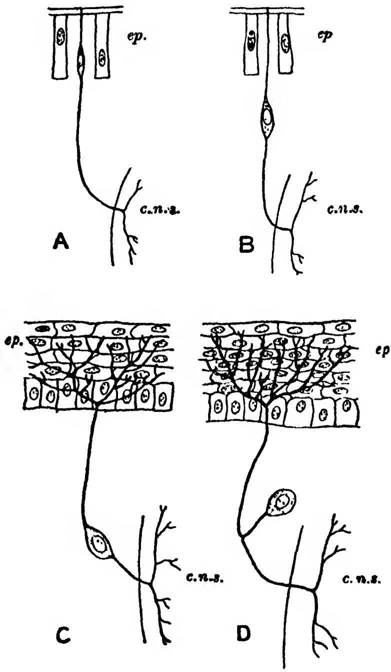


FIG. 112.—A diagram showing the mode of ending of the sensory nerve fibres of the earthworm and the relation of this type to that which is found in most of the sensory fibres of the frog. See also Fig 51.

A, The arrangement found in the earthworm; *B*, that of the *Nereis*; *C*, that of a fish; *D*, that of a frog or man.
c.n.s., Ending of the neuron in the central nervous system; *ep.*, ending in the epidermis.

nerve cord. The nephrostome consists of a large crescentic *central cell* with a rim of *marginal cells* around it arranged so as to surround a crescentic, funnel-shaped opening, turned to one side. The funnel is ciliated, and from it there leads backwards a narrow ciliated tube. This passes through the septum to the main part of the nephridium,

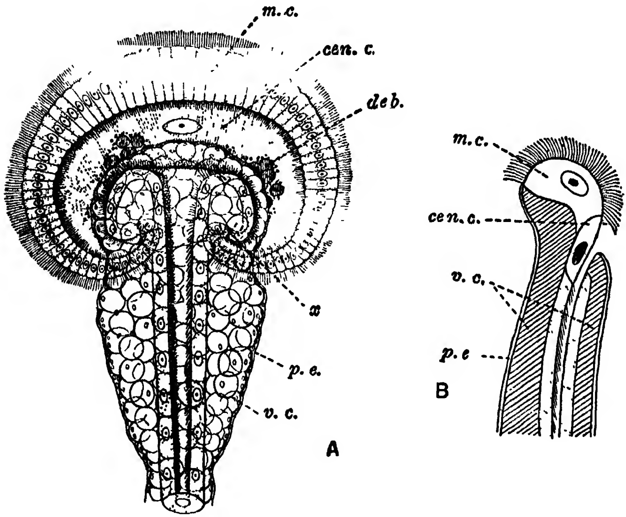


FIG. 113.—The nephrostome or funnel of a nephridium on the earthworm. *A*, in surface view, highly magnified; *B*, in longitudinal section, diagrammatic.

cen.c., Central cell; *deb.*, débris of cœlomic corpuscles and excretory granules which are probably not able to enter the funnel; *m.c.*, marginal cells; *p.e.*, peritoneal epithelium; *v.c.*, vesicular connective tissue cells; *x.*, point at which the marginal cells join the lining of the tube, which turns over round the opening.

which lies behind the septum, in the cœlom of the next segment, opening to the exterior by the nephridiopore in that segment. The narrow part of the tube is long and winding and loses its cilia in places. It is followed by a wider, short, brown region, ciliated throughout, this by a still wider tube which is not ciliated, and finally a short, very wide, muscular tube leads to the nephridiopore. The whole tube, except the muscular region, is formed of

hollow cells shaped like drain pipes and lying end to end. The cilia set up a stream of cœlomic fluid which carries off the substances taken from the blood and excreted by the walls of the tubes. Some of these, in the form of granules, colour the brown part of the tube. Earthworms have no special *respiratory organs*, but an interchange of

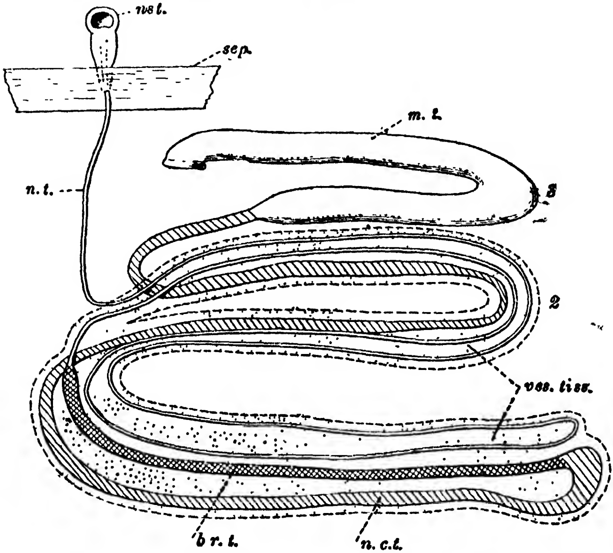


FIG. 114.—A diagram of a nephridium of the earthworm.

br.t, Brown, ciliated tube; *m.t.*, muscular tube; *n.c.t.*, glandular, non-ciliated tube; *n.t.*, narrow tube, ciliated in parts; *nst.*, nephrostome; *sep.*, septum; *ves.tiss.*, connective tissue with vesicular cells and blood-vessels; 1, 2, 3, the three hanks of the tube.

For details of structure see Fig. 110.

gases with the air takes place in the skin, which is richly supplied with blood vessels.

Blood Vessels. The blood of an earthworm is red on account of the presence of hæmoglobin, which is in solution, not in corpuscles. Colourless corpuscles are present. The blood-vascular system is very complicated. Its main outlines are as follows. A large *dorsal vessel* runs the whole length of the body from the hinder

end to the pharynx. It is contractile, and in it the blood is driven forwards. This vessel supplies blood to, and receives it from, the gut directly and the rest of the body indirectly. It communicates by many small vessels with the intestine and by two large vessels in the tenth segment with the œsophagus, and ends in front by breaking up into branches which supply the pharynx. In each of the segments 7–11 it gives off a pair of large contractile vessels or *pseudo-hearts*. These encircle the œsophagus and join a *ventral or subintestinal vessel* which hangs by a

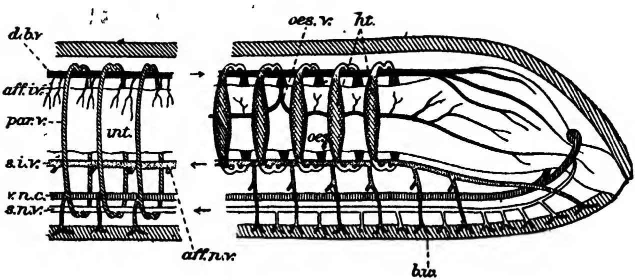


FIG. 115.—A diagram of the blood-vascular system of the earthworm. *aff.i.v.*, Afferent vessels of the intestine; *aff.n.v.*, afferent vessels of the nephridia; *b.w.*, body-wall; *d.b.v.*, dorsal blood vessel; *ht.*, pseudo-hearts; *int.*, intestine; *œs.*, œsophagus; *œs.v.*, œsophageal vessel; *par.v.*, parietal vessel; *s.i.v.*, subintestinal vessel; *s.n.v.*, subneural vessel; *v.n.c.*, ventral nerve cord.

mesentery below the gut. In the pseudo-hearts the blood flows downwards from the dorsal to the ventral vessel, and in the latter it flows backwards. From the ventral vessel the blood passes along branch vessels partly to the nephridia and partly to the skin. Purified by these organs, it is returned along various paths to the dorsal vessel. Among the subsidiary vessels are a *subneural* and two *lateral neural vessels*, in which the blood flows backwards, and *parietal vessels*, of which a pair in each segment of the intestinal region of the body connect the subneural with the dorsal vessel. The main blood vessels of the earthworm cannot be distinguished into arteries and veins, but their ends are joined by capillaries.

Earthworms are hermaphrodite, every individual having a complete set of organs of each sex. The *female organs* include the ovaries, oviducts, and spermathecæ. The ovaries are two small, pear-shaped bodies hanging into the cœlom of the thirteenth segment from the septum in front of it. Each ovary is a local thickening of the cœlomic epithelium. The broad end of the pear is attached to the septum and contains a fused mass of unripe ova. Maturation divisions take place at the base of the stalk, which contains the ripe eggs. These fall from it into the body cavity and are taken up by the oviducts, which open by wide funnels into the cœlom in the thirteenth segment, pass through the septum behind, and open to the exterior in the fourteenth. In the latter segment, each bears a swelling, the *receptaculum ovorum or egg sac,* in which the eggs are stored. The *spermathecæ* are two pairs of small, round sacs which lie in the ninth and tenth segments and open in the grooves behind them. Their function is to receive sperm from another worm. The *male organs* consist of testes, vesiculæ seminales, and vasa deferentia. These testes are two pairs of small, flat, finger-lobed bodies attached to the hinder side of the septa in front of segments 10 and 11. They are local thickenings of the cœlomic epithelium like the ovaries, to which they correspond in position. The testes bud off cells known as *sperm-mother-cells,* which give rise to spermatozoa in the

Reproduction.

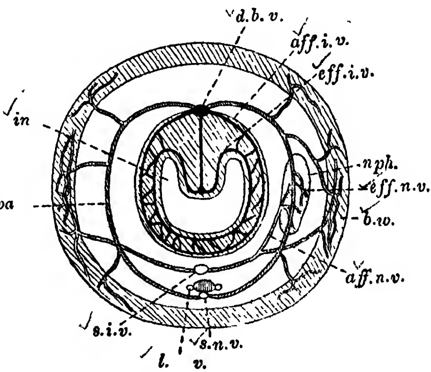


FIG. 116.—A diagram of a transverse section of the earthworm in the intestinal region to show the arrangement of the blood vessels. Lettering as in Fig. 115.

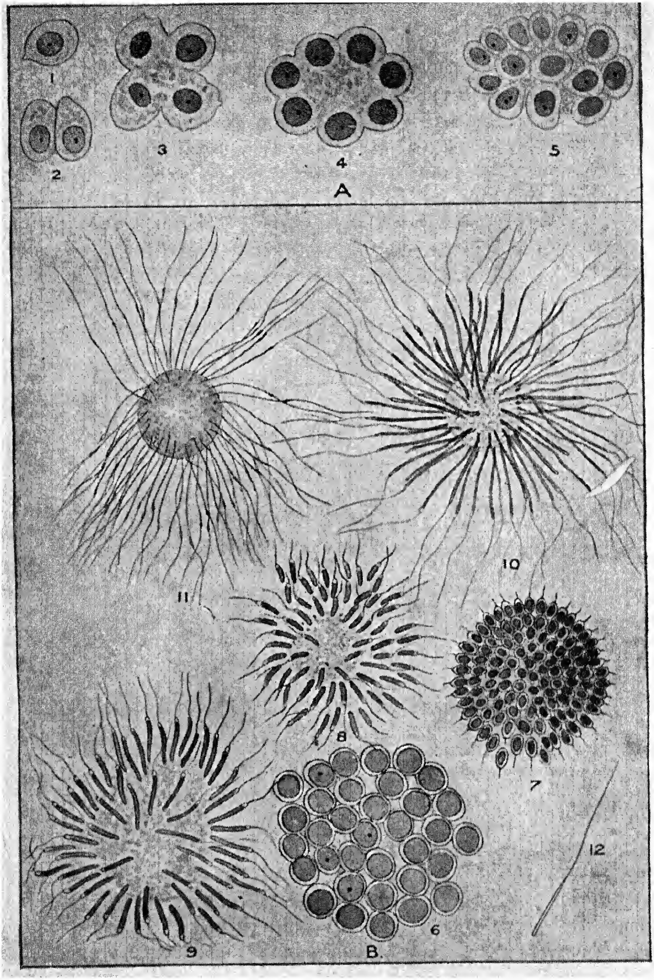


FIG. 117.—The development of the spermatozoa ot the earthworm.

A, Stages from the vesicula seminalis of a young worm ; *B*, from that or an older worm.

1, Sperm mother-cell ; 2–7, stages in the division to form spermatozoa ; 7–11, shaping of the spermatozoa, which are still adherent to the mass of residual protoplasm (cytophore) ; 12, a ripe spermatozoon, unstained. The head in 12 is represented rather too broad.

The dark bodies are the nuclei, stained.

vesiculæ seminales. The latter are large sacs, formed by the walling-off of parts of the cœlom, which enclose the testes. Each consists of a median part and lateral horns. The anterior vesicula seminalis, in segment 10, has four lateral horns, two in front and two behind, which push out the septa and bulge into the ninth and eleventh segments. The posterior vesicula seminalis, in segment 11, has only two such horns, which project into the twelfth segment. Each sperm-mother-cell forms by multiple fission, in the course of which the usual reduction division takes place, a mulberry-like mass (Fig. 117) consisting of little cells attached to a central mass of residual protoplasm known as the *cytophore*, by which they are nourished. The little cells become pear-shaped, with the broad ends on the cytophore, gradually increase in length, and change their shape till the mulberry has become a tuft of threads, each thread being a spermatozoon with a very slender head. Finally the spermatozoa break loose. In the median part of each vesicula seminalis, directly behind the testes, is a pair of large ciliated funnels with folded walls, known as *sperm rosettes*. These funnels lead into the vasa deferentia, of which the two on each side join and pass backwards to open on segment 15. The cilia of the rosettes draw the ripe sperm into the ducts.

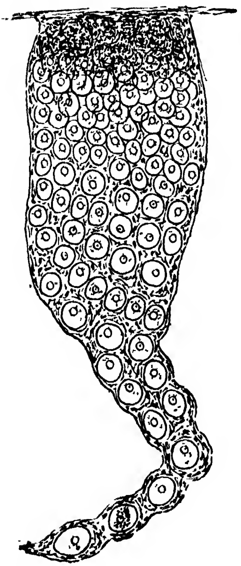


FIG. 118.—One of the ovaries of an earthworm.

Pairing takes place at any time from spring to autumn in warm, damp weather. Two worms stretch themselves out of their burrows and place their ventral sides together with the heads pointing in opposite directions, their bodies being held together by a substance secreted from the clitella. Sperm is passed from the vas deferens of each

worm, along a groove, into the spermathecæ of the other, after which the worms separate. The eggs are laid in a cocoon, which is secreted by the clitellum as a broad band round the body and passed forwards over the head. The cocoon contains a nutrient fluid, and into it sperm which has been received from another worm is transferred in a little packet or spermatophore. In passing over the head

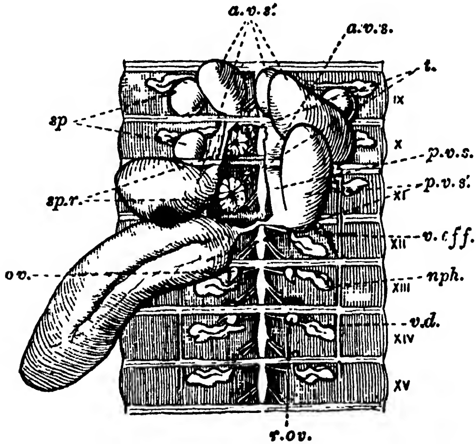


FIG. 119.—A dissection of the reproductive organs of an earthworm. The dissection is made from above, and the median parts of the vesiculæ seminales have been opened on the left-hand side.

a.v.s., Anterior vesicula seminalis; *a.v.s'.*, horns of the same; *n.p.h.*, nephridium; *o.v.*, ovary; *p.v.s.*, posterior vesicula seminalis; *p.v.s'.*, horns of the same; *r.ov.*, receptaculum ovorum (the funnel of the oviduct lies immediately in front); *s.p.*, spermathecæ; *sp.r.*, sperm rosettes (funnels of the vasa efferentia); *t.*, testes; *v.d.*, vas deferens; *v.eff.*, vasa efferentia.

the ends of the elastic cocoon close, and it becomes a small, lemon-shaped body, which is left in the earth. Each cocoon contains three or four ova, which are fertilised in it, but usually only one completes its development.

Regeneration. Earthworms have an extensive power of regeneration, though it is not so great as that of *Hydra*. If the body be cut in half, the head end will grow a new tail, and the tail end, though more slowly, a new head.

Mesoderm, Cœlom, and Hæmocœle.

In comparing the body of an earthworm with those of the other examples of the Metazoa that we have studied, it will be seen that in one respect of importance it resembles the frog rather than *Hydra*. The body of *Hydra* consists of two epithelia—the ectoderm and endoderm—with only a structureless lamella between them. In a frog or an earthworm these epithelia reappear as the epidermis and the lining epithelium of the gut, but between them is a great mass of tissue which comprises the skeletal tissues, muscles, excretory and generative organs, and so forth. These tissues are together known as the *mesoderm*, and animals which possess this third layer are known as *Triploblastica*, whilst those, like *Hydra*, which possess only two are *Diploblastica*. Both in the earthworm and in the frog the mesoderm contains cavities of two kinds, the *primary body cavity or hæmocœle or blood vessels*, and the "*true*" *or secondary body cavity or cœlom*. The functions of the cœlom are threefold. (1) It forms a *perivisceral cavity*, which surrounds the principal viscera and gives room for their movements. (2) From its walls are derived the generative cells. This is clearly seen in the case of the ova, which are shed into the perivisceral cavity, but it is less clear in the case of the spermatozoa, because these are developed in special vessels, derived from the cœlom, but closed. (3) It is concerned in excretion. In an earthworm, where the yellow cells of its walls form excreta which are expelled from the body, this is more obvious than in the frog, but the latter possesses in the tadpole stage (and, according to some authorities, also in the adult) funnels which, like those of the nephridia of the earthworm, pass cœlomic fluid into the excretory tubules, where it serves to wash out the waste products. The hæmocœle is a system of spaces of more complex form than the cœlom, and rarely (p. 193) perivisceral. Its function is to contain the blood and lymph. A blood-vascular system is made necessary in most triploblastic animals by the presence of the great mass of internal tissues which constitute the mesoderm.

Another feature of the morphology of an earthworm to which attention must be called here is its *segmentation*. We have found merism or the repetition of parts in all

our animal types. In an earthworm the whole body consists of similar divisions arranged one after the other in a line or series. These divisions are the segments. Each contains a ring of the body-wall, with setæ and openings, a separate portion of the cœlom, a section of the gut, a ganglion, nephridia, and blood vessels. A body so constructed is said to be *metamerically segmented*. Most of the segments resemble one another closely, but in the forepart of the body they show considerable differences in the reproductive, alimentary, and other organs. The body of an earthworm is composed of similar divisions, because all the organs are repeated together at regular intervals. There are other animals in which only some of the organs are thus repeated, as in the frog, where the vertebræ, nerves, and to some extent the muscles exhibit segmentation, so that the regions of which the body might be regarded as composed are much less alike than they are in the earthworm. In such cases segmentation is said to be incomplete. The tapeworm presents an example of a kind of segmentation which is very complete, but is of quite a different nature from that of the earthworm, the youngest segments being at the front end and the old ones dropping off, whereas in the earthworm the youngest segments are those at the hind end and the animal does not shed its segments.

Segmentation.

Segmented, cœlomate animals, with a thin cuticle, a closed blood-vascular system, and nephridia and a nervous system like those of the earthworm, are known as *Annelida*. The earthworm, the lugworm (*Arenicola*), often used for bait, and leeches belong to this group.

Annelida.

CHAPTER XI

THE CRAYFISH. ARTHROPODA

Habits.

CRAYFISHES are found in many English rivers, especially in those which rise in chalk or limestone hills. They are little, lobster-like creatures, which make burrows in the river banks. They dislike strong light and during the daytime generally remain in their holes with only their pincers and long feelers projecting. When they come out they crawl stealthily about, searching constantly for their food, which consists of organic matter of any kind, plant or animal, dead or alive, that they are able to seize and break up with their pincers. If danger threatens, they dart backward suddenly and swiftly. They are used for food, especially for garnishing salads, and were formerly caught in large numbers in this country by means of wicker crayfish-pots, but in 1887 their numbers were greatly reduced by a disease, and at present crayfishes for the table are imported from the Continent.

External Features.

The English crayfish, *Astacus torrentium*, is about three inches long, and of a dull, greenish colour, which harmonises well with the surroundings in which it lives. The species imported from the Continent is *A. fluviatilis*, which is larger and has red colouring on the pincers and legs. The body of a crayfish is covered with a cuticle thickened and strengthened by salts of lime to form an armour: it is segmented, each segment bearing a pair of jointed limbs, but in the front part the segments are fused to form a *fore-body or cephalothorax*, where the only conspicuous sign of their existence is the presence of several pairs of limbs, though careful examination shows that parts of the armour and certain internal organs are also segmentally arranged. The rest of the

body, known as the *hind body or abdomen*, is more completely segmented. At the end of the abdomen is a flat piece known as the *telson*, on the under side of which the anus opens. The telson bears no limbs, and is divided by an imperfect transverse joint. The armour of each segment of the abdomen consists of a broad back-piece or *tergum* and a narrow belly-plate or *sternum*, with a pair of V-shaped prolongations, known as the *pleura*, joining them at the sides. There are no pleura on the first abdominal segment. The tergum, sternum, and pleura of each segment form a continuous ring. The limbs are jointed to the hinder side of the sternum near its outer ends, and the part of the sternum between each limb and the adjoining pleuron is sometimes called an *epimeron*. The terga overlap one another from before backwards and slide over one another as the abdomen is straightened and bent, the armour of each segment being joined to that of the next by thin cuticle, which allows of movement. In the cephalothorax the terga are fused to form a *shield or carapace*. This is prolonged in front into a beak-like *rostrum* and is crossed by a furrow, which is called the *cervical groove* because it is supposed to mark the separation of two regions known as the head and thorax. At each side of the body a fold of the carapace overhangs as a lean-to roof, the *gill cover or branchiostegite*, which encloses between itself and the side of the body a chamber in which the gills lie. Behind the cervical groove a *branchiocardiac groove* on each side marks off the branchiostegite from a median *cardiac region* which roofs the thorax. The cuticle of the inside of the branch-

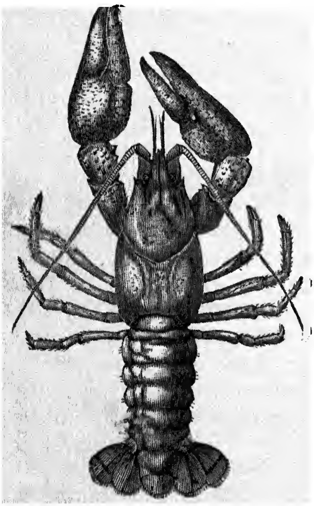


FIG. 120.—View of a crayfish from above.—After Huxley.

Note cervical groove, cardiac region of carapace, rostrum, and tail fan.

iostegite and part of the side of the body underneath it are thin. On the ventral side of the cephalothorax the limbs of each pair are close together, but small sterna lie between them. The head is, of course, the region which contains the mouth and the principal sense organs. The mouth is placed on the ventral surface at some distance from the front end, and in front of it the sternal surface slopes upwards to the rostrum. At the sides of the latter, upon a pair of short, movable stalks, are placed the eyes, and below these stand two pairs of feelers or antennæ.

Limbs.

The *limbs or appendages* number nineteen pairs, without counting the eyes, which are by some authorities reckoned as limbs. We shall not take this view, but as there is evidence in the development of the crayfish and of related animals that the foremost region of the head corresponds to a segment, we shall regard the body as containing twenty segments, of which the foremost bears no limbs. The telson is not a segment. Of the twenty segments, the first six form the head, the next eight the thorax, and the last six, with the telson, the abdomen. The parts of which a complete limb consists are best seen in the limbs known as the third pair of maxillipeds (Fig. 123, A), which lie immediately in front of the great pincers. In each of these we may distinguish a two-jointed basal region or *protopodite*, the joint nearest the body being known as the *coxopodite*, the next as the *basipodite*. On its outer side the coxopodite bears a large, flat, thin-walled structure known as the *epipodite*, covered with small finger-processes, which constitute a *gill*. At the base of the epipodite is a knob bearing a tuft of threads known as the *coxopoditic setæ or setobranch*. The basipodite bears two structures. From its outer side arises a slender, jointed appendage known as the *exopodite*. At its end, continuing the axis of the limb, is the stout, five-jointed *endopodite*, whose joints, starting from the basipodite, are known as the *ischiopodite*, *meropodite*, *carpopodite*, *propodite*, and *dactylopodite*. The other limbs are built upon the same general plan as the third maxilliped, but in detail the structure of every one of them is adapted to the particular work it has to perform, each part being of a different shape in each pair of limbs, or sometimes

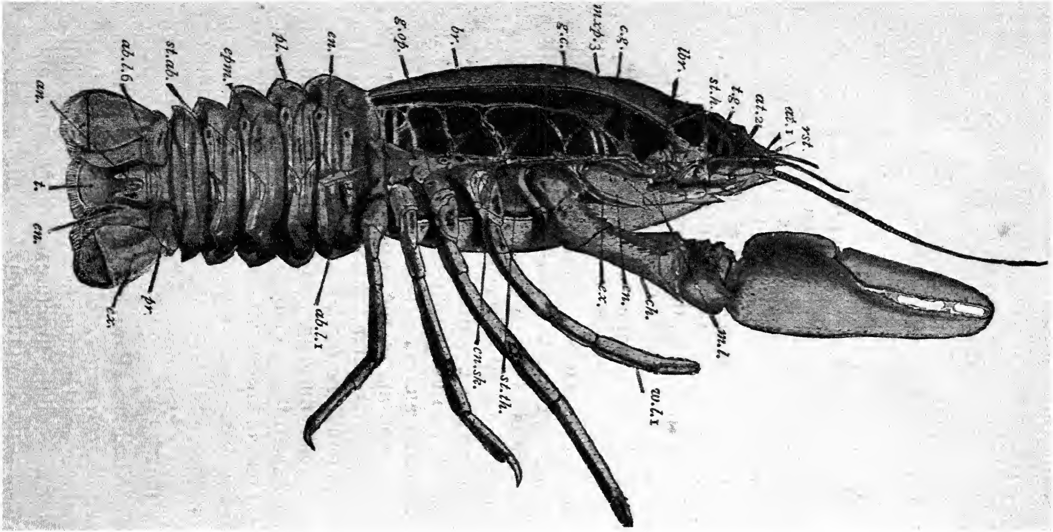


FIG. 121.—A ventral view of a female crayfish, with the limbs of the right side removed and the branchiostegite of that side partly cut away.—Partly after Howes.

*ab.l.*1,6, First and sixth abdominal limbs; *at.*1, antennule; *at.*2, antenna; *an.*, anus; *br.*, branchiostegite; *c.g.*, cervical groove; *ch.*, cheliped; *en.*, endopodite; *en.sk.*, endophragmal skeleton; *epm.*, epimeron; *ex.*, exopodite; *g.c.*, gill chamber; *g.op.*, openings of oviduct; *lbr.*, labrum; *m.l.*, limbs adjoining the mouth; *mxp.*3, third maxilliped; *pl.*, pleuron; *pr.*, protopodite; *rst.*, rostrum; *st.ab.*, abdominal sterna; *st.h.*, sternal region of body in part of mouth; *st.th.*, thoracic sterna; *t*, telson; *t.g.*, tubercle on which green gland opens; *w.l.*1, first walking leg.

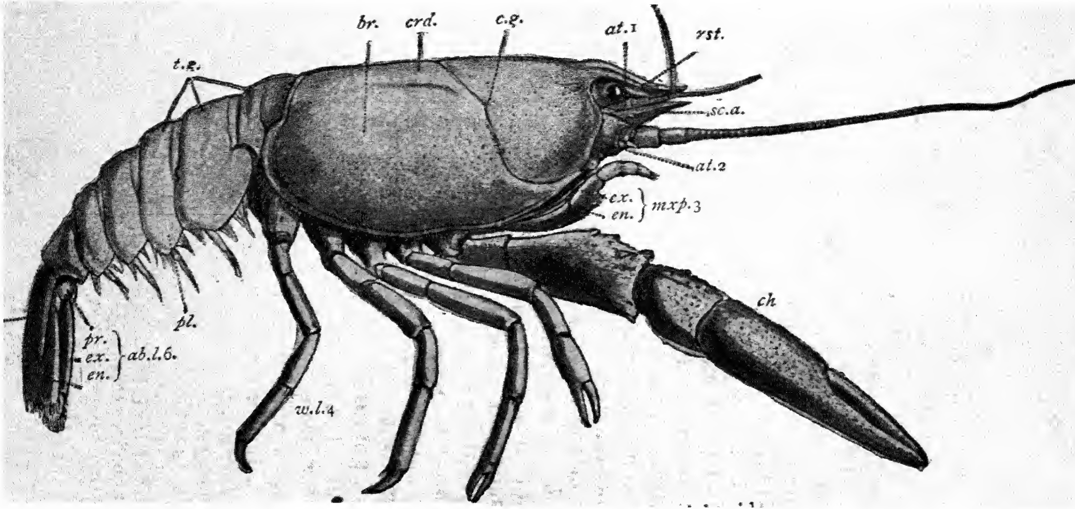


FIG. 122.—View of a crayfish from the right side.

ab.l.6, Sixth abdominal limb; *at.1*, antennule; *at.2*, antenna; *br.*, branchiostegite; *c.g.*, cervical groove; *ch.*, cheliped; *crd.*, cardiac region of carapace; *en.*, endopodite; *ex.*, exopodite; *mxp.3*, third maxilliped; *pl.*, pleuron; *pr.*, protopodite; *rst.*, rostrum; *sc.a.*, scale of antenna; *t.*, telson; *tg.*, terga; *w.l.4*, last walking leg.

absent altogether. The first two pairs are sensory, and have long lashes for searching the surroundings of the animal. The next six pairs are jaws, used for bringing the food to the mouth and chewing it: these are short and stand close behind the mouth. Then come two great shears or pincers which are the principal grasping organs, next four pairs of legs, and then the six pairs of limbs of the abdomen, of which some are concerned in reproduction, some help the animal forward by paddling while it is walking, and the last pair are used in rapid swimming. Exopodites are wanting from the legs, great pincers, and first two pairs of jaws, and epipodites are found only upon the limbs of the thorax.

The first limb of each side is known as the *antennule or first antenna.* It is peculiar in having three, instead of two, joints in its protopodite. The first joint [1] is large and three-sided: upon its upper side there opens, by a slit edged with bristles, the statocyst, which will be described later. The third joint bears two many-jointed lashes or flagella. These are often compared to the exopodites and endopodites of the other limbs, but it is not certain that the comparison is justifiable. The outer lash bears on the under side of most of its joints certain peculiar bristles which are supposed to serve the sense of smell. The second limb is the *antenna* (or *second antenna*). Its coxopodite is short and wide and bears below a knob, upon which opens the green gland or kidney. The basipodite is divided lengthwise into two pieces. The exopodite is a flat, triangular, pointed *scale*, and the endopodite is a very long flagellum. The third limb or *mandible* has a large, broad, and very strong coxopodite [2] with a toothed *incisor edge* which bites against that of its fellow on the other side of the body. Above the incisor edge, and therefore hidden

[1] See the following note.

[2] Perhaps really a joint known as the *precoxa*, which corresponds to the first joint of the antennule and is in the maxillule separated from the basipodite by a small basal piece representing the coxopodite There is reason to believe that the so-called coxopodite of the mandible is a precoxa, the true coxopodite being absent. In the second maxilla the precoxa may be represented by the first lobe of the protopodite, and in the thorax the precoxa of each limb is absorbed into the side of the body. There is no evidence as to its identity in the abdominal limbs.

in ventral view, is a broad, irregular ridge known as the *molar process*. The basipodite and an endopodite of two joints form a small three-jointed appendage or *palp* in front of the coxopodite. The mandibles lie at the sides of the mouth. Behind it come the limbs of the fourth pair, known as the *maxillules or first maxillæ.* Each of these consists of three

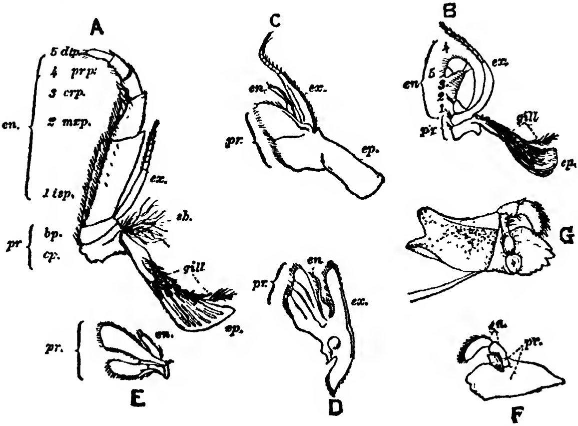


FIG. 123.—The mouth appendages of the left side of a crayfish.

A, Third maxilliped; *B*, second maxilliped; *C*, first maxilliped; *D*, maxilla (second maxilla); *E*, maxillule (first maxilla); *F*, mandible in ventral view; *G*, the same in dorsal view, showing molar process.

bp. Basipodite; *cp.*, coxopodite; *crp.*, carpopodite; *dtp.* dactylopodite; *en.*, endopodite; *ep.*, epipodite; *ex.*, exopodite; *gill*; *isp.*, ischiopodite; *mrp.*, meropodite; *pr.*, protopodite; *prp.*, propodite; *sb.*, setobranch or tuft of coxopoditic setæ; 1–5, joints of endopodite.

thin plates joined to a small basal piece. One plate is an expansion of the coxopodite,[1] the second represents the basipodite, and the third the endopodite. The fifth limb is the *maxilla* (or *second maxilla*). It is a flat structure, deeply cleft into several parts. The protopodite bears two thin lobes directed towards the middle line of the body and each in turn divided into two.[2] The endopodite is a narrow

[1] See note 2 to p. 188.

[2] The first double lobe probably represents the precoxa and coxopodite; the two parts of the second lobe probably belong to the basipodite.

structure directed forwards. The exopodite is a wide plate projecting backwards and forwards from the outer side of the limb and known as the *scaphognathite.* The second maxilla lies under the front end of the branchiostegite, and the function of the scaphognathite is to set up a current of water over the gills by baling it forwards out of the gill chamber. The sixth limb, or *first maxilliped,* is the first of those which belong to the thorax. Two broad lobes represent its coxopodite and basipodite, the endopodite is small and two-jointed, and the exopodite, shaped like that of the third maxilliped, is large. The epipodite is present as a very large plate, which does not bear a gill. The *second maxilliped* is much like the third, but has a smaller en-

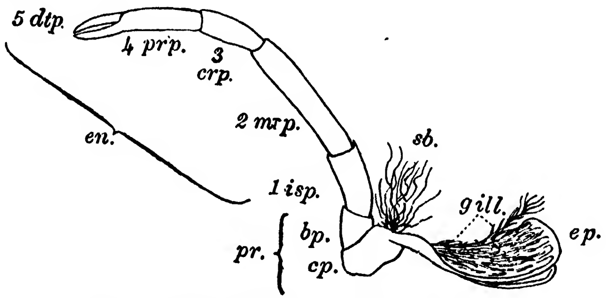


FIG. 124.—The first walking leg of a crayfish. Letters as in Fig. 123.

dopodite and a relatively larger exopodite. The *third maxilliped* has already been described. Behind the maxillipeds come five pairs of *legs or pereiopoda,* of which the first, the ninth of the whole series of limbs, bear great pincers and are called the *chelipeds,* the rest being the *walking legs.* In each of these limbs the exopodite is wanting and the endopodite is long and strong and consists of five joints, named as in the third maxilliped. In the chelipeds and the walking legs of the first two pairs the last joint but one has a projection, against which the last joint bites so as to form a pair of pincers. An epipodite bearing a gill is present upon each of the legs except the last pair. On the coxopodite of the second walking leg of the female is a round opening, through which the eggs are laid, and the sperm of the male

is passed through a similar opening upon the last leg. Of the *abdominal limbs* the first and second pairs are best studied after the third, fourth, and fifth. The latter are alike and consist each of a short coxopodite, a long basipodite, and an endopodite and exopodite each composed of a number of imperfectly separated joints, of which the first is longer than the rest. The endopodite is rather longer than the exopodite, and both bear numerous, plumed bristles. The *second abdominal limb* of the female is like those behind it. In the male the first joint of the endopodite is much elongated and bears at the end on the outside a thin plate rolled into a scroll. The *first abdominal limb* has no exopodite in either sex. In the female it is minute. In the male the basipodite and endopodite are fused, flattened, and rolled scrollwise into a tube for conveying sperm to the female. The limbs of the *last* (*sixth*) *abdominal pair* have short, undivided protopodites, and very broad endopodites and exopodites, the former of one, the latter of two joints. They are directed backwards, and form with the telson the *tail fan* used in swimming.

Table of the Segments of the Crayfish

Head .	1.	Preantennal limbless segment	
	2.	Antennules . . .	Sensory limbs.
	3.	Antennæ (II) . .	
	4.	Mandibles . . .	Jaws.
	5.	Maxillules . . .	
	6.	Maxillæ (II) . .	
Thorax .	7.	Maxillipeds (I) . .	
	8.	,, (II) . .	
	9.	,, (III) . .	
	10.	Chelipeds . . .	Legs.
	11.	Walking legs (I) . .	
	12.	,, ,, (II) ♀ .	
	13.	,, ,, (III) .	
	14.	,, ,, (IV) ♂ .	
Abdomen	15.	Abdominal limbs (I) .	Uniramous limbs.
	16.	,, ,, (II) .	Paddles.
	17.	,, ,, (III) .	
	18.	,, ,, (IV) .	
	19.	,, ,, (V) .	
	20.	,, ,, (VI) .	Tail fan.
		Telson . . .	

♀ Female opening. ♂ Male opening.

The ectoderm or epidermis of the crayfish consists of a layer of protoplasm with nuclei, which in many parts is not divided into cells and is therefore a syncytium (p. 120), though in places it forms a columnar epithelium. Outside it, lies a cuticle which it secretes, and, as we have already seen, this cuticle is for the most part thick and hardened with salts of lime, so as to form an armour, but remains thin and flexible in certain places so as to form joints which allow the parts of the body to move upon one another, and also in the gill chambers. In many places it bears bristles of various shapes. These are hollow, and the epidermis is continued into them and is here often connected with nerve fibres, so that the bristles serve as sense organs of various kinds. From time to time the cuticle is shed and a new one secreted. This allows of growth and also serves as a form of excretion, for the horny basis of the cuticle, known as *chitin*, is a complex compound of ammonia, so that in it the animal gets rid of nitrogenous waste matter. Moulting takes place frequently while the animal is growing, but the full-grown male sheds its cuticle only twice a year, and the female only once. As the time for moulting draws near, the crayfish goes into hiding, because the new cuticle is soft and the animal will be helpless for some days while it is hardening. The shell then splits across the back and along the limbs, and the crayfish, lying on its side, draws itself out of the old cuticle.

Cuticle and Epidermis.

There is in the crayfish no continuous muscular body-wall, but numerous muscles, composed of striped fibres, move the various parts of its body, being attached to the inside of the pieces of the armour. Thus the skeleton is external, not, like that of a frog, internal. In the thorax ingrowths of the cuticle provide a kind of false internal skeleton. This has the form of a complicated scaffolding along the ventral side of the animal, and is known as the *endophragmal skeleton.* Two sets of muscles move the abdomen. A dorsal set of *extensor muscles* starts from the inside of the carapace and is inserted into the terga of the abdominal segments. When they contract, these muscles draw forward the terga and thus straighten the abdomen. On the ventral side

Skeleton, Muscles, and Locomotion.

another, more powerful, set of muscles connects the sterna with one another and with the endophragmal skeleton. These, when they contract, draw closer the sterna and thus bend the abdomen. By this movement, spreading at the same time its tail fan, the crayfish carries out the sudden backward jumps by which it escapes from its enemies. Its gentle forward movements are carried out by the walking legs, aided by a paddling of the abdominal limbs. The legs of the first three pairs pull and those of the last pair push, and their movements are carried out in such a way that the animal is always standing upon six legs while two—which are on opposite sides and of different pairs—are in motion.

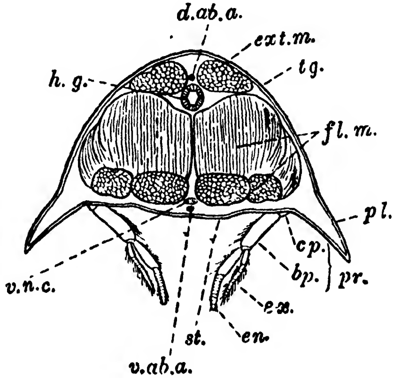


FIG. 125.—A semi-diagrammatic drawing of a transverse section of the abdomen of the crayfish.

bp., Basipodite; *cp.*, coxopodite; *d.ab.a.*, dorsal abdominal artery; *en.*, endopodite; *ex.*, exopodite; *ext.m.*, extensor muscles; *fl.m.*, flexor muscles; *h.g.*, hind-gut; *pl.*, pleuron; *pr.*, protopodite; *tg.*, tergum; *st.*, sternum; *v.ab.a.*, ventral abdominal artery; *v.n.c.* ventral nerve cord.

Perivisceral Cavity and Alimentary System.

The body of the crayfish contains a spacious perivisceral cavity, in which the internal organs lie. This is not a cœlom, but an enlarged portion of the hæmocœle (p. 181), and communicates with the blood vessels. The alimentary canal fills the greater part of this cavity. The mouth is an elongated opening below the head between the mandibles. It is bordered in front by a wide *upper lip or labrum*, and behind it stands a pair of lobes known together as the *lower lip or metastoma*. A short, wide *gullet* leads upwards into the large *proventriculus*, often called the "stomach." This consists of two chambers, a large *forepart or mill-chamber*, often known as the "cardiac division of the stomach," and

a smaller *hind part or filter-chamber*, often known as the "pyloric division of the stomach," separated from the

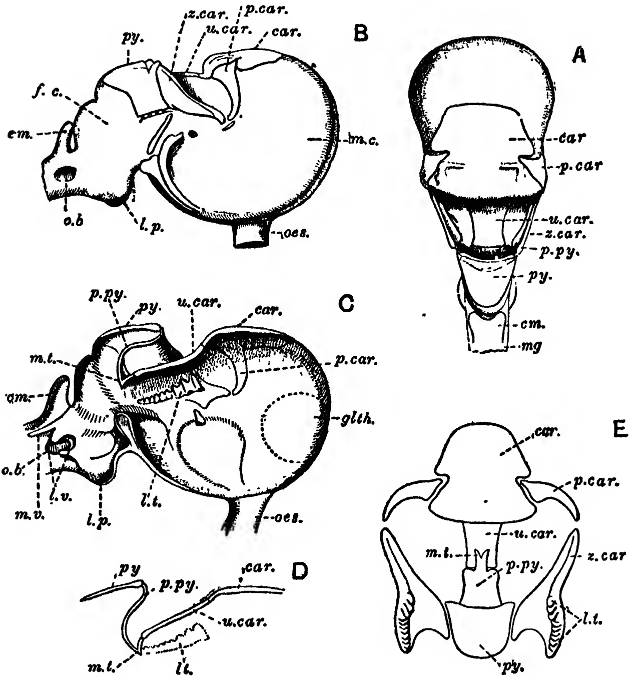


FIG. 126.—The proventriculus of the crayfish.

A, The whole organ from above; *B*, the same from the right side; *C*, the left half from within, the muscles being relaxed; *D*, the ossicles of the mill in median section, the anterior and posterior gastric muscles being contracted; *E*, the mill in plan. All the figures are semi-diagrammatic, much detail being omitted.

car., Cardiac ossicle; *cm.*, cæcum; *f.c.*, pyloric or filter-chamber; *glth.*, position of gastrolith; *l.p.*, lateral pouch; *l.t.*, lateral tooth; *l.v.*, lateral valves guarding opening into mesenteron; *m.c.*, mill-chamber; *m.t.*, median tooth; *m.v.*, median valve; *o.b.*, opening of bile duct; *œs.*, œsophagus; *p.car.*, pterocardiac ossicle; *p.py.*, prepyloric ossicle; *py.*, pyloric ossicle; *u.car.*, urocardiac ossicle; *z.car.*, zygocardiac ossicle.

mill-chamber by a pit in the roof. From the filter-chamber the short *mid-gut or mesenteron* leads backwards to the long *hind-gut*, sometimes called the "intestine." The epidermis

and cuticle turn inwards at the mouth and line the gullet and proventriculus, which are together known as the *fore-gut*. The mid-gut is lined with soft endoderm, and the hind-gut is again lined with epidermis and cuticle. Thus the regions often called stomach and intestine in the crayfish do not correspond with those so named in the frog and earthworm, being lined with ectoderm, not endoderm. The cuticle in the gut is for the most part thin, but in places in the proventriculus it forms stout plates or ossicles, certain of which bear strong teeth which project into the forepart of the organ. By the action of muscles these can be brought together to crush the food. The whole apparatus is known as the *gastric mill*.

Two large plates lie across the roof in the two divisions, and are known as the *cardiac* and *pyloric ossicles*. They are joined in the middle by two smaller pieces, the *urocardiac* and *prepyloric ossicles*, which lie respectively in the front and hinder walls of the pit between the two divisions. From the lower end of the prepyloric ossicle there projects into the proventriculus the forked *middle tooth*. When the mill is at rest the pit passes backwards, so that the prepyloric ossicle in its hinder wall is also directed backwards under the pyloric, and its tooth points backwards. At each side of the pit the cardiac and pyloric ossicles are connected by two more pieces, the *zygocardiac ossicle*, which articulates behind with the side of the pyloric, and the *pterocardiac ossicle*, which joins the front end of the zygocardiac to the side of the cardiac ossicle. These side ossicles do not run straight, but slope outwards to meet at an angle, so that the outline of the whole framework of the mill is roughly hexagonal. Internally each zygocardiac ossicle bears a large, ribbed, *lateral tooth*. *Anterior* and *posterior gastric muscles* run from the cardiac and pyloric ossicles respectively to the carapace. When they contract they pull these ossicles apart. The result is that (1) the upper end of the prepyloric ossicle, being pulled backward by the pyloric, stands upright, thus turning the middle tooth forwards; (2) the zygocardiac and pterocardiac ossicles are straightened out, so that the lateral teeth are brought together in the middle line. Thus all three teeth meet inside the proventriculus. The ossicles are brought back to their former position partly by the elasticity of the walls of the proventriculus and partly by the contraction of *cardiopyloric muscles* (Fig. 127).

The filter-chamber is also complicated, having various internal ridges covered with bristles which serve to strain out the particles of the food, so that only the finely crushed matter passes into the mid-gut. Into this opens on each side the *liver or hepatopancreas*, a large, lobed, yellow

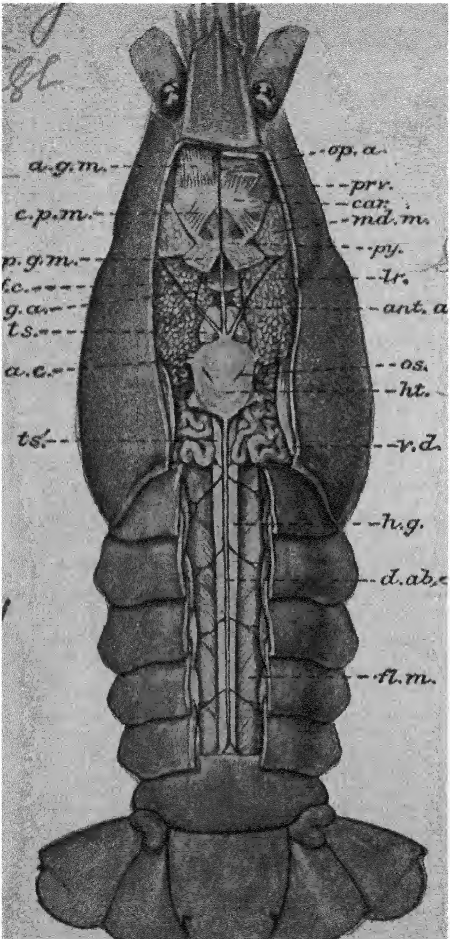


FIG. 127.—A male crayfish dissected from the dorsal side, after injection of the arteries.

a.c., ala cordis; *a.g.m.*, anterior gastric muscle; *ant.a.*, antennary artery; *c.p.m.*, cardiopyloric muscle; *car.*, cardiac ossicle; *d.ab.a.*, dorsal abdominal artery; *f.c.*, part of filter chamber, blue coloured in fresh specimens; *fl.m.*, flexor muscles of abdomen; *g.a.*, gastric artery; *h.g.*, hind-gut; *ht.*, heart; *lr.*, liver; *md.m.*, muscle of mandible; *op.a.*, ophthalmic artery; *os.*, ostium; *p.g.m.*, posterior gastric muscle; *prv.* proventriculus ("cardiac" division); *py.*, pyloric ossicle; *ts.*, anterior lobe of testis; *ts'.*, posterior lobe of the same; *v.d.*, vas deferens.

gland, consisting of numerous short tubes joined by ducts which finally communicate with the mid-gut by an opening on each side. The roof of the mid-gut is prolonged into a short *blind gut or cæcum.* Food is either raked up by the third maxillipeds or seized by the chelipeds and torn up by them and the smaller pincers. It is passed forwards by the jaws to the mouth, where it is cut up by the mandibles into pieces small enough to be swallowed. These are chewed in the proventriculus, strained, and in a finely divided state passed into the mid-gut. The juice secreted by the liver digests all classes of food-stuffs, and digestion and absorption take place within the liver as well as in the mid-gut. The cuticle of the gut is shed with that of the body. Shortly before a moult two flat calcareous bodies, known as "*crab's eyes*" *or gastroliths*, are laid down in the forepart of the proventriculus. They are ground up before the moult takes place. It is uncertain whether they consist of matter removed from the armour of the body to weaken it in preparation for the moult or are a store of material for the strengthening of the new cuticle. Possibly they serve both purposes.

Blood Vessels.

The heart is a hollow organ with thick, muscular walls. It is roughly hexagonal in outline, as seen from above, and lies in the thorax, above the hind-gut and immediately below the cardiac region of the carapace, in a space, known as the *pericardial sinus*, with membranous walls, to which the heart is connected by six fibrous bands called the *alæ cordis.* Three pairs of valved openings or *ostia* admit blood from the pericardial sinus to the heart: one pair is dorsal, another lateral, and the third ventral. From the front end of the heart arise three vessels—a median *ophthalmic artery*, which runs straight forwards over the proventriculus to supply the eyes and other organs of the head, and a pair of *antennary arteries*, which start one on each side of the ophthalmic, run forwards and outwards, and divide each into two branches, one *gastric* and the other to the antennæ and green gland. Behind and below the antennaries arise a pair of *hepatic arteries*, which supply the liver, and from the hinder angle of the heart there is given off a vessel which at once divides into a *dorsal abdominal artery*, which runs backwards above

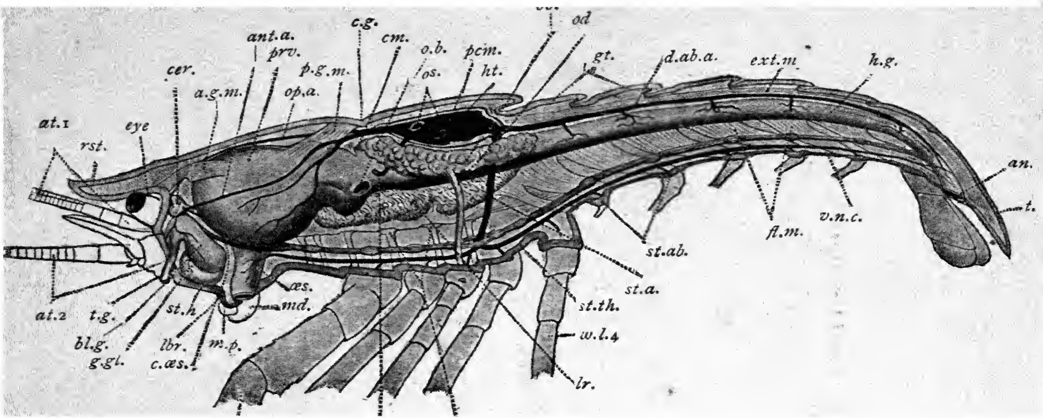


FIG. 128.—A female crayfish dissected from the left side.—Partly after Shipley and MacBride.

a.g.m., Anterior gastric muscle; ***an.***, anus; ***ant.a.***, antennary artery; ***at.1***, antennule; ***at.2***, antenna; ***bl.g.***, bladder of the green gland; ***c.g.***, cervical groove; ***c.æs.***, circumœsophageal commissure; ***cer.***, cerebral ganglion; ***ch.***, cheliped; ***cm.***, cæcum; ***d.ab.a.***, dorsal abdominal artery; ***en.sk.***, endophragmal skeleton; ***eye***; ***ext.m.***, extensor muscles; ***fl.m.***, flexor muscles; ***g.gl.***, green gland; ***h.g.***, hind-gut; ***hep.a.***, hepatic artery; ***ht.***, heart; ***lr.***, liver; ***lbr.***, labrum; ***md.***, mandible; ***m.p.***, mandibular palp; ***o.b.***, opening of bile duct; ***od.***, oviduct; ***æs.***, œsophagus; ***op.a.***, ophthalmic artery; ***os.***, ostia; ***ov.***, ovary; ***p.g.m.***, posterior gastric muscle; ***pcm.***, pericardium; ***prv.***, proventriculus; ***rst.***, rostrum; ***st.a.***, sternal artery; ***st.ab.***, abdominal sterna; ***st.h.***, sternal region of the body in front of the mouth; ***st.th.***, thoracic sterna; ***t.***, telson; ***t.g.***, tubercle for green gland; ***tg.***, terga; ***v.n.c.***, ventral nerve cord; ***w.l.4***, last walking leg.

the intestine and supplies it and the muscles of the abdomen, and a *sternal artery.* This passes downwards, through an opening in the ventral nerve cord, and divides into a *ventral abdominal* and a *ventral thoracic artery*, by which the limbs are supplied. Each of the arteries

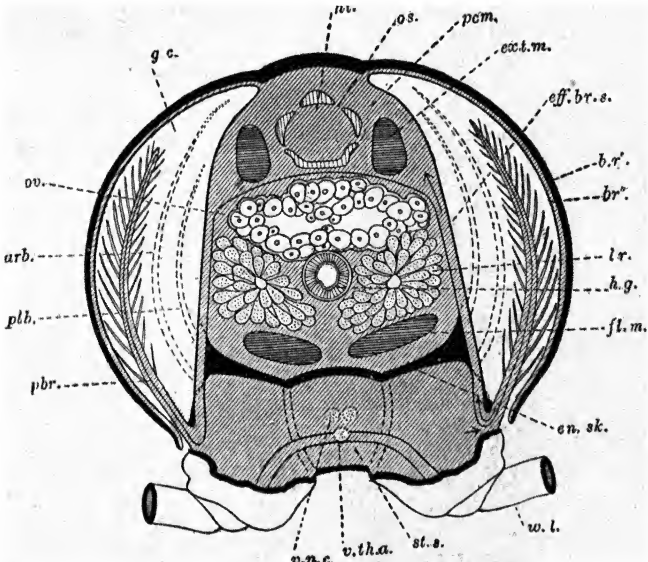


FIG. 129.—A diagram of a transverse section through the thorax of a crayfish.

arb., Arthrobranch; *br'.*, outer layer of branchiostegite; *br''.*, inner layer of the same; *eff.br.s.*, efferent branchial sinus; *en.sk.*, endophragmal skeleton; *ext.m.*, extensor muscle of abdomen; *fl.m.*, flexor muscles of abdomen; *g.c.*, gill-chamber; *h.g.*, hind-gut; *ht.*, heart; *lr.*, liver; *os.*, ostia; *ov.*, ovary; *pcm.*, pericardium; *pbr.*, podobranch; *plb.*, pleurobranch; *st.s.*, sternal sinus; *v.n.c.*, ventral nerve cord; *v.th.a.*, ventral thoracic artery; *w.l.*, walking leg.
Small arrows in the sinuses on the right-hand side show the course of the circulation of the blood.

branches many times, till it finally gives rise to minute vessels in the organs it supplies, but there are no capillaries.

It will be seen that in the crayfish, as in the earthworm, there is a dorsal contractile blood vessel, but that in the crayfish the contractile organ—the heart—is very short and

wide, and is prolonged in front and behind by non-contractile vessels—the ophthalmic and dorsal abdominal arteries. We shall find in the cockroach a similar but longer heart.

From the organs the blood passes into great *sinuses* which surround them. The largest of these is the perivisceral cavity, but there are also blood spaces in the limbs and elsewhere. The blood from the limbs and a great part of that from the perivisceral cavity is gathered up into a *sternal sinus*, which lies in a tunnel formed by the endo-

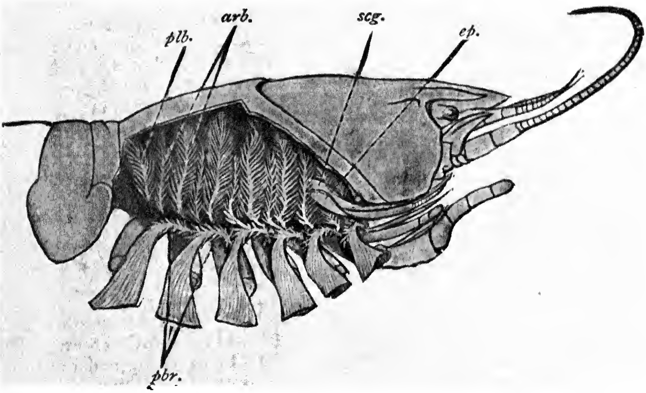


FIG. 130.—The forepart of the body of a crayfish, viewed from the right-hand side, with the legs and the branchiostegite cut away and the gills displayed.

arb., Arthrobranchiæ; *ep.*, epipodite of the first maxilliped; *pbr.*, podobranchiæ; *plb.*, pleurobranchia; *scg.*, scaphognathite.

phragmal skeleton and contains the ventral nerve cord and ventral thoracic artery. From this a series of *afferent branchial sinuses* carries the blood to the gills, where it is oxygenated. From the gills it passes by *efferent branchial sinuses* to the pericardial sinus. Part of the blood from around the stomach, however, passes on each side into the space between the two sides of the fold of carapace which forms the branchiostegite, and thence to the pericardial sinus by a vessel which follows the hinder edge of the branchiostegite. It will be noted that the pericardial cavity of the crayfish is a part of the hæmocœle and contains blood, un-

like that of the frog, which is a separate part of the cœlom. A blood-vascular system in which, as in the crayfish, the blood on leaving the arteries bathes the organs of the body is said to be *open*. One in which, as in the worm and the frog, it is carried through the organs in capillaries which lead direct to veins is said to be *closed*. The blood of the crayfish is a clear fluid, which contains white corpuscles and clots readily—an obvious advantage to an animal whose open vascular system causes it to bleed freely from any wound. An organic compound of copper, known as *hæmocyanin*, which is dissolved in it, plays the same part as hæmoglobin, taking up oxygen in the respiratory organs and parting with it to the tissues. In the oxidised condition it is of a blue colour and tinges the blood.

FIG. 131.—A podobranch of the crayfish, seen from behind.

Base; *cp.*, coxopodite; *gill*; *lam.*, lamina; *sb.*, setobranch or tuft of coxopoditic setæ; *stm.*, stem.

Respiratory Organs.

The respiratory apparatus of the crayfish is contained in the gill-chambers. The *gills* are branched, thin-walled structures, standing upon the coxopodites of the thoracic limbs and the inner wall of the gill-chamber. In them the blood circulates and exchanges its carbon dioxide for the oxygen which is dissolved in the water that is kept flowing through the chamber by the action of the second maxilla. This limb is held firm by the curved end of its endopodite, which fits into a groove upon the mandible at the base of the palp, while the exopodite or scaphognathite, flapping at the rate of sixty strokes a minute, bales water forwards, out of the gill-chamber and under the opening upon the antenna of the green gland, whose excreta it thus sweeps away with the foul water from the gills. By this action fresh water is drawn into the chamber between the bases of the legs. No doubt the blood

in the branchiostegite is oxygenated through the thin inner wall of that organ.

The gills receive different names according to their position. Those which are attached to the epipodites of the limbs are known as *podobranchiæ*. Others stand upon the membranes which join the limbs to the body, and are known as *arthrobranchiæ*, and a few stand upon the inner wall of the gill-chamber (the side wall of the thorax) above the legs, and are known as *pleurobranchiæ*. A podobranchia is found on every thoracic limb, except the first pair of maxillipeds, which have no gills,[1] and the last pair of legs, which have only a pleurobranchia. Two arthrobranchiæ, an anterior and a posterior, are found upon each limb that has a podobranchia, except the second maxilliped, which has only the anterior arthrobranchia. Well-developed pleurobranchiæ are only found above the legs of the last pair, but in the same position above each leg of the three preceding pairs there is a minute process which represents a gill. The following table shows the position of the gills :—

	Maxillipeds.			Legs.					Total.
	I.	II.	III.	I.	II.	III.	IV.	V.	
Podobranchiæ .	Ep	1	1	1	1	1	1	0	6+Ep
Anterior arthrobranchiæ . .	0	1	1	1	1	1	1	0	6 } 11
Posterior arthrobranchiæ . .	0	0	1	1	1	1	1	0	5 }
Pleurobranchiæ	0	0	0	0	R	R	R	1	1+3R
Total . .	Ep	2	3	3	3+R	3+R	3+R	1	18+3R+Ep

Ep=epipodite without a gill. R=abortive rudiment.

Each arthrobranchia has a tree-like structure, consisting of a trunk or *axis* arising from the body by one end, with numerous short branches or *filaments*. The two pleurobranchiæ have the same structure. In the podobranchiæ the axis is fused to the epipodite along the greater part of its length, so that the filaments appear to arise from the epipodite. The tip of the gill, however, stands free. The epipodite itself is a long plate with a wide *base*, a narrower *stem*, and at the end a second expansion, the *lamina*. The stem and lamina are folded along the length of the epipodite, so that a groove is formed, into which fits the gill of the limb next behind.

[1] In *A. fluviatilis* they have each a vestigial arthrobranchia.

The excretory organs of the crayfish are known as the *green glands*. They lie in the head, immediately behind the antennæ, upon whose basal joints their ducts open. The duct is connected with a thin-walled bladder, below which lies a green mass. This has a complicated structure, which may be summed up by saying that it is a labyrinth of spaces whose walls are lined by a cubical, glandular epithelium differing in character in different regions. In the middle of it is a small, brownish sac whose cavity is divided by partitions and communicates by a single opening with the labyrinth. This is known as the *end sac*. The labyrinth has been compared to a nephridium, but more probably belongs to a class of mesodermal tubes known as "cœlomoducts," of which we shall meet with further examples. The end sac is a minute portion of the cœlom, which is otherwise represented in the crayfish only by the cavity of the genital organ.

Excretory Organs.

In its general plan the nervous system of the crayfish resembles that of the earthworm. In the front part of the head, between the green glands, lies a *supra-œsophageal or cerebral ganglion, or brain*, which corresponds in position to the supra-pharyngeal ganglia of the worm. It gives nerves to the eyes, antennules, and antennæ, and from it two long *circumœsophageal commissures* pass backwards to join behind the œsophagus in the *subœsophageal ganglion*. This gives nerves to the limbs as far as the second maxillipeds inclusive, and immediately behind it lies the *first thoracic ganglion*, which supplies the third maxillipeds. In each of the remaining segments of the thorax lies an indistinctly double ganglion which supplies by several nerves the limbs and other organs of its segment. These ganglia are set at some distance apart and are connected by double commissures, forming thus a *ventral cord*. Between the fourth and fifth ganglia the commissures part widely to allow the sternal artery to pass between them. In the abdomen the cord is continued and consists of a ganglion in each segment united to its fellows by longitudinal commissures, which are really double, but appear at first sight to be single. The last ganglion supplies the telson as well as its own segment.

Nervous System.

A *transverse commissure* immediately behind the œsophagus joins the two circumœsophageal commissures. It contains fibres which take this roundabout course between the portions of the brain which supply the antennæ, thus indicating that these limbs belong to the same series as those behind the mouth. This is probably also true of the antennules, and the fact that the antennules and antennæ are innervated from the supraœsophageal ganglia must be connected with the position of the mouth, which, as a result of cephalisation to a high degree, is farther back than in the earthworm, where it lies in front of the first segment. The alimentary canal is supplied by two *visceral nerves*. The first has a threefold origin, being formed by the junction of a nerve from the cerebral ganglion with two nerves which arise

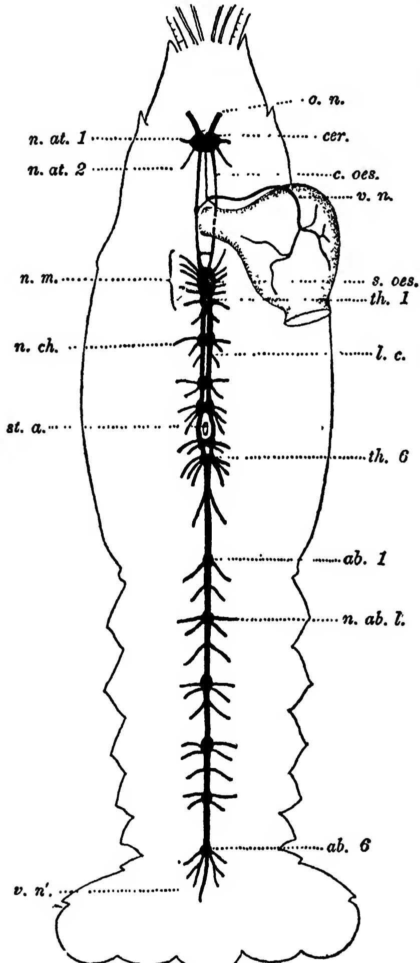


FIG. 132.—A semi-diagrammatic view of central nervous system of a crayfish.

*ab.*1, *ab.*6, The first and sixth abdominal ganglia; *cer.*, cerebral ganglion; *c.œs.*, circumœsophageal commissure; *l.c.*, longitudinal commissures of ventral cord; *n.ab.l.*, nerves to abdominal limbs; *n.at.*1, nerve to antennule; *n.at.*2, nerve to antenna: *n.ch.*, nerve to cheliped; *n.m.*, nerves to limbs adjoining the mouth; *o.n.*, optic nerve; *s.œs.*, subœsophageal ganglion; *st.a.*, sternal artery; *th.*1, *th.*6, first and sixth thoracic ganglia; *v.n.*, nerve to proventriculus; *v.n'.*, nerve to hind-gut.

each from a small ganglion on the course of the circumœsophageal commissure. The second arises from the last abdominal ganglion.

Sense Organs. The *eyes* of the crayfish are *compound*, containing a number of elements, known as *ommatidia*, each of which is a small complete eye. The whole eye is black, owing to the presence of pigment in some of its cells, and is covered with a colourless portion of the cuticle known as the *cornea*, divided into a number of square facets, each of which corresponds to an ommatidium. The structure of the ommatidia is complex: each is an elongated body consisting of a number of cells derived from the epidermis with refractive bodies secreted by them. The innermost cells form a group known as the *retinula*, whose inner ends are continued into nerve fibres. The ommatidia are separated by pigment cells and the retinular cells also contain pigment. The way in which such eyes give rise to vision has been the subject of various theories. It appears that the pigment flows about within the cells, being retracted in weak light and expanded in strong. When it is retracted the eye gives a single image; when it is expanded each retinula gives a separate image, sharper but formed with a greater loss of light than that given when the eye acts as a whole. No doubt this *mosaic* of images is combined in the nervous system to give a single impression.

The *statocysts* are a pair of sacs, situated in the basal joints of the antennules and provided with nerves. Each has a cuticular lining beset with hairs, with which the nerve fibres are in communication. Within it are grains of sand, which are scattered over the opening of the sac by the pincers and fall into it. It is probable that the principal function of the organ is informing the animal of its position by the movements of the sand grains against the hairs, and thus enabling it to keep its equilibrium. If the statocysts be removed, the crayfish loses its sense of position and will often swim upside down. Experiments upon the prawn, an animal related to the crayfish, illustrate the function of the statocysts. A prawn that had lost the lining of its statocysts with the sand grains by moulting was kept in filtered water and supplied with finely powdered iron in place of sand. When it had placed some of these in its

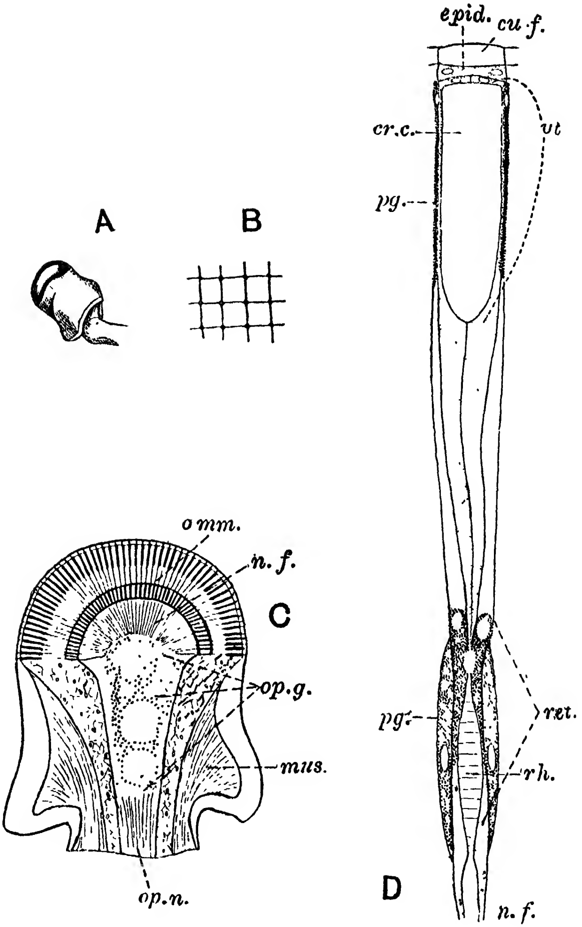


FIG. 133.—The eye of the crayfish.

A, The left eye removed; *B*, a portion of the cornea magnified to show the facets; *C*, a longitudinal section of the eye under low magnification; *D*, a single ommatidium highly magnified.—*D* after Parker.

cr.c., Outer refractive body or crystalline cone; *cu.f.*, cuticular facet; *epid.*, epidermis (hypodermis); *mus.*, muscles which move the eye; *n.f.*, nerve fibres; *omm.*, ommatidia; *op.g.*, optic ganglion; *op.n.*, optic nerve; *p.g.*, outer pigment cells; *pg'.*, inner pigment cells; *ret.*, retinula cells (the sense cells)—these cells contain pigment; *rh.*, inner refractive body or rhabdome; *vt.*, vitrellæ or cells which secrete the crystalline cone.

statocysts, a magnet was brought near it, and by moving the magnet the particles of iron were caused to move as they would be by a change in the position of the animal. By this means the prawn was made to alter its position in

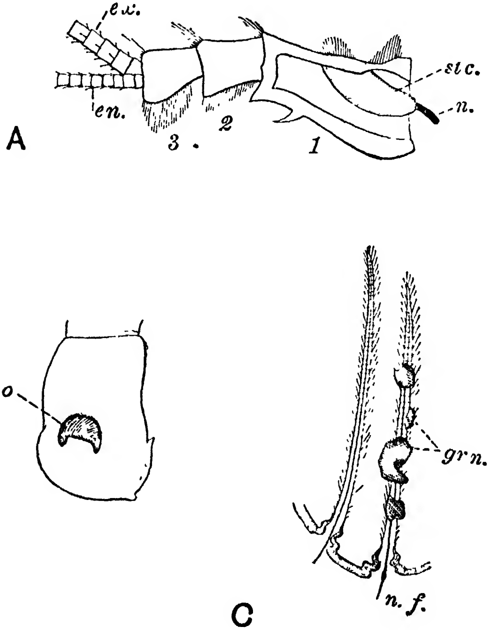


FIG. 134.—The statocyst of the crayfish.

A, The right antennule, seen from the median side with the basal joint opened and the flagella cut short; *B*, basal joint of the left antennule from above; *C*, two hairs from the statocyst.—*C* partly after Howes.

en., Inner flagellum; *e.x.*, outer flagellum; *grn.*, sand grains; *n.*, nerve of the statocyst; *n.f.*, nerve fibres; *o.*, opening of the statocyst; *stc.*, statocyst.

correspondence with the movements of the magnet. It was formerly supposed that the statocysts subserved the sense of *hearing*, but though the animals appear to perceive vibrations, and this may be due to the statocysts, it is doubtful whether the latter are true organs of hearing. We have seen

that the antennules bear on their outer flagella bristles which subserve the sense of *smell.* Various of the setæ, especially those of the antennæ, are organs of *touch.*

Reproduction. The sexes of the crayfish are separate. The generative organs lie in the thorax, above the gut and below the pericardium. They have the same general shape in the two sexes, consisting of three lobes, two anterior and one posterior, with a pair of ducts, which start from the junction of the anterior and posterior lobes and run to the limbs on which they open. The ovary is

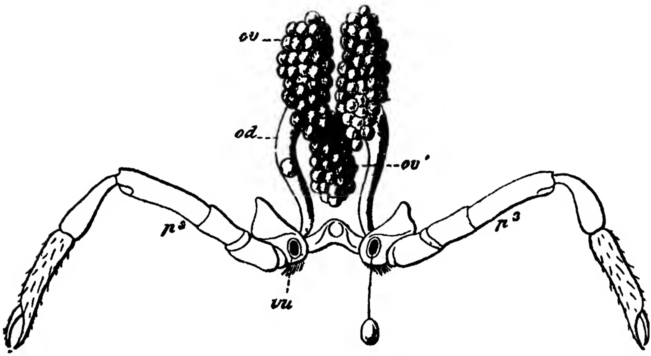


FIG. 135.—The reproductive organs of a female crayfish.—After Suckow.

od., Oviduct; *ov.*, ovaries; *ov'.*, fused posterior part (median lobe); *vu.*, female aperture on the second walking leg (p^3).

larger and broader than the testis, and has an internal cavity into which the eggs are shed. The oviducts are short, straight, and wide; they open upon the coxopodites of the second pair of walking legs. The testes consist of a number of branching ducts which end in small alveoli, in which the spermatozoa are formed. The vasa deferentia are narrow and much coiled; their first part is very slender and translucent, the second part, which forms most of the duct, is wider and glandular, and a short terminal region has muscular walls which force out the sperm. The *spermatozoa* are discs with stiff, pointed processes round the edge. Inside the disc is a round capsule and

to one side of this a small, oval body. Pairing takes place in September and October. The male seizes the female, throws her upon her back, and passes sperm through the tubular limbs of his first abdominal segment on to the parts in the neighbourhood of her oviducts, the limbs of his second abdominal pair aiding the process by working to and fro on the hollows of the first. The sperm consists of a sticky substance, secreted by the vasa deferentia, carrying the spermatozoa, and forms white masses on the sterna of the female. The eggs, which are large and yolky, are laid in November. The processes of the spermatozoa adhere to them, and by a sudden expansion of the capsule the rest of the body is forced into the ovum. Each egg is attached to one of the hairs on the abdominal limbs by a stalked shell formed of a substance secreted by certain glands on the sterna, and is thus under the protection of the mother during its development. By the division of the nucleus of the fertilised ovum a syncytium is formed which does not divide into cells until a number of nuclei have arisen. The young are hatched at the beginning of the next summer. They do not differ greatly from the adult, but have curved tips to the pincers, by which they cling for a time to the empty shell or the abdominal limbs of the mother, and are thus protected from enemies and kept from being swept away by currents and so eventually reaching the sea, where they would perish.

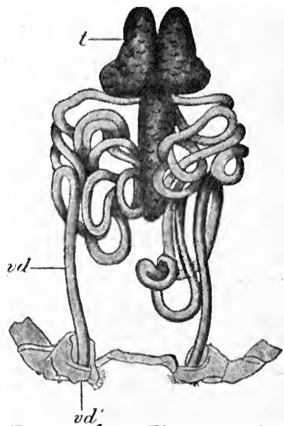


FIG. 136. — The reproductive organs of a male crayfish.— After Huxley.

t, Testes; *vd.*, vas deferens; *vd'.*, opening of vas deferens on last walking leg.

The power of regeneration, though it is less in the crayfish than in earthworms and much less than in *Hydra*, is still considerable. A whole limb which is injured can

be grown again. The injured leg is first cast off by a spasmodic contraction of some of its muscles which causes it to break through at the basipodite, the internal cavity being here crossed by a partition which leaves only a small opening, through

Regeneration and Autotomy.

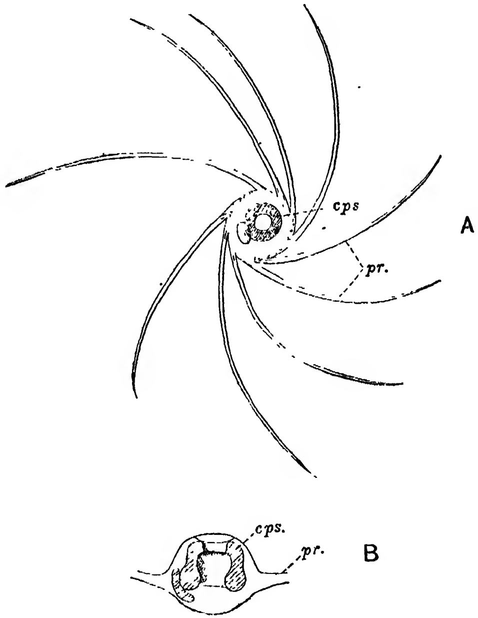


FIG. 137.—Spermatozoa of a crayfish.

A, Whole spermatozoon from above; *B*, part, enlarged, in section. *cps.*, Capsule; *pr.*, stiff processes.

which the nerves and blood vessels pass. When the limb is cast off this opening is quickly closed by a blood clot, after which the cuticle grows across the wound. Beneath the scar the new limb is formed as a sort of bud and gradually takes shape. At the next moult it becomes free, though it is still small, and it increases in size at each moult, until a normal limb has been provided. This

power of casting off limbs is known as *autotomy.* It is sometimes used as a means of escape from enemies which have seized one of the limbs, but this is not so common in the crayfish as in some animals that are related to it.

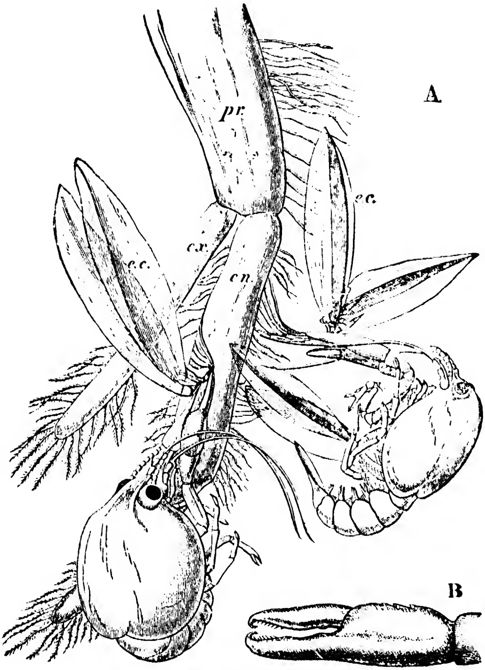


FIG. 138.—*A*, Two recently hatched crayfish holding on to one of the swimmerets of the mother; *B*, pincers of such crayfish more highly magnified.—From Huxley.

e.c., Ruptured egg cases; *en.*, endopodite; *ex.*, exopodite; *pr.*, protopodite.

Arthropoda. Segmented animals with jointed limbs, a thick cuticle, an open blood-vascular system, and a nervous system like that of the crayfish are known as *Arthropoda.* Crustaceans (waterfleas, shrimps, prawns, crayfish, crabs, etc.), Insects, Arachnida (scorpions, spiders,

mites, ticks, etc.), and Centipedes belong to this group. Crustaceans have two pairs of antennæ and are almost all water animals, breathing by gills. Insects have one pair of antennæ and are usually land animals, breathing by air tubes and provided with wings. They have six legs. Arachnids have no antennæ, nearly all breathe air by various devices, and have no wings, but eight legs. The Arthropoda are far more numerous than any other group of animals, and are of the greatest importance to man, partly because some of them serve him as food, but more because they damage his crops, annoy him as parasites, and in sucking his blood convey to him the germs of very serious diseases.

CHAPTER XII

THE COCKROACH

COMMON as they now are, cockroaches have only been introduced into England comparatively recently. The first specimens were brought from the East by trading vessels at the beginning of the seventeenth century, and one hundred and fifty years later Gilbert White could still speak of the cockroach as "an unusual insect" at Selborne. This species was the Common Cockroach, *Periplaneta orientalis.* More recently another species, *P. americana*, a native of tropical America, has been introduced and is spreading rapidly. Both are nocturnal insects which haunt human dwellings, hiding in corners and crevices by day. They seek warmth, as is natural in view of their origin, and devour any kind of food they can find.

Cockroaches.

In its main lines the anatomy of a cockroach resembles that of a crayfish. The animal is segmented, the segments being unlike and grouped into three regions known as head, thorax, and abdomen, but these do not correspond with the parts similarly named in the crayfish. There is a thick cuticle, and jointed limbs are found on the head and thorax. The thorax bears also two pairs of wings. At the sides of the head lie a pair of large, unstalked, compound eyes. The cœlom, of which traces are found in development, disappears in the adult, but there is a hæmocœlic perivisceral cavity containing blood.

Anatomy of a Cockroach.

The head is short and deep. Seen from in front it has a pear-shaped outline, with the narrow end downwards. Its armour consists of several pieces—two *epicranial plates* side by side above, two *genæ* at the sides below the eyes, and a *clypeus* in front. A labrum

Head.

is hinged on to the clypeus below. The appendages of the head are as follows: There is one pair of long, slender, unbranched, many-jointed antennæ, corresponding to the

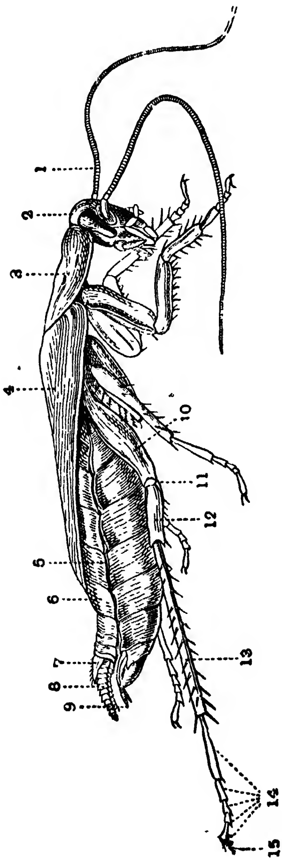


FIG. 139.—A male of the Common Cockroach (*P. orientalis*) in side view.—From Shipley and MacBride.

1, Antenna; 2, head; 3, prothorax; 4, fore wing; 5, soft skin between terga and sterna; 6, sixth abdominal tergum; 7, split portion of tenth abdominal tergum; 8, anal cerci; 9, styles; 10, coxa of third leg; 11, trochanter; 12, femur; 13, tibia; 14, tarsus; 15, claws.

antennules of the crayfish. The second antennæ of the latter are not represented in the cockroach. The mandibles are stout, toothed structures without palps, not unlike the basal parts of those of the crayfish. The

maxillules of the crayfish are not represented in the cockroach, though in certain primitive insects corresponding structures are present. The maxillæ consist of (*a*) a protopodite of two joints known as the *cardo* and *stipes*, (*b*) a five-jointed endopodite known as the *maxillary palp*, (*c*) two lobes—an inner *lacinia* and a softer outer *galea*—borne on the stipes to the median side of the palp. Behind the maxillæ lie a pair of appendages which correspond in position to the first maxillipeds of the crayfish, but are here known sometimes as the second maxillæ, though better as the *labium*. Their protopodites are fused so that they form a single lower lip. The first joint of their common protopodite is the *submentum*, the second the *mentum*. This bears on each side an endopodite or *labial palp* of three joints, set upon a projection of the mentum known as the *palpiger*. At the end of the mentum stand two lobes. Their basal parts are fused, liked the protopodites, forming a structure, known as the *ligula*, which is deeply notched at its free end. On each side of the notch it bears an inner lacinia and an outer *paraglossa*. It will be seen that the head of the cockroach contains one segment more than that of the crayfish.

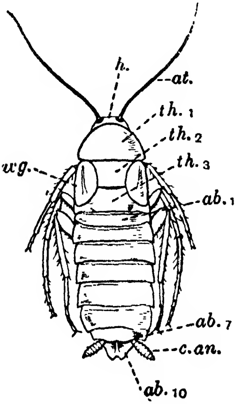


FIG. 140.—A female of the common cockroach. The body is somewhat compressed so as to show the membranes between the abdominal terga. The legs are not in the attitude characteristic of the living animal.

*ab.*1–*ab.*10, Abdominal terga; *at.*, antenna; *c.an.*, anal cerci; *h.*, head; *th.*1, prothoracic tergum; *th.*2, mesothoracic tergum; *th.*3, metathoracic tergum; *wg.*, vestige of fore wing.

The head is joined by a soft neck to the thorax. This consists of three segments—the prothorax, mesothorax, and metathorax. Each has a tergum or *notum* above and a sternum below. The pronotum is the largest and projects in front so as to hide the neck. Each segment bears a pair of legs. The shape of these legs and the names of their joints are shown

Thorax.

in Fig. 139. The third and fourth joints bear bristles which are used in cleaning the body, and the last joint bears two hooked claws used in climbing and between the claws a pad or *pulvillus* which prevents slipping. The mesothorax and metathorax bear each a pair of wings jointed to the anterior corners of the notum. The wings are membranous folds of the cuticle strengthened by ridges known as *nervures*. The first pair are dark-coloured and horny and form a cover for the second, which, when they are at rest, are folded lengthwise and laid along the back. In the female of *P. orientalis* the wings are very small. Wings are not appendages of the same kind as the limbs, but movable expansions of the terga.

Abdomen.

The abdomen consists of ten segments, each with a tergum and a sternum, joined at the sides by soft cuticle. The hinder segments are telescoped, so that the eighth and ninth

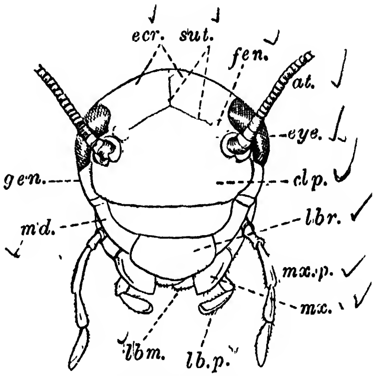


FIG. 141.—The head of a cockroach, seen from in front.

at., Antenna; *clp.*, clypeus; *ecr.*, epicranium; *eye*; *fen.*, fenestra; *gen.*, gena; *lbm.*, part of the labium; *lb.p.*, labial palp; *lbr.*, labrum; *md.*, mandible; *mx.*, part of the maxilla; *mx.p.*, maxillary palp; *sut.*, sutures.

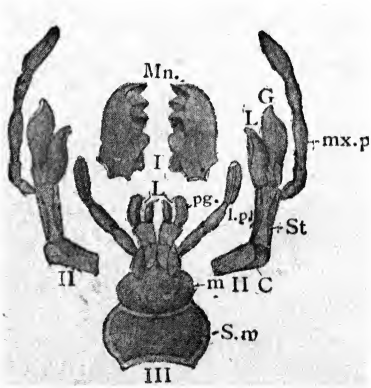


FIG. 142.—The mouth appendages of a cockroach.—After Dufour.

I, *Mn.*, mandibles; II, maxillæ; *C.*, cardo; *St.*, stipes; *L.*, lacinia; *G.*, galea; *mx.p.*, maxillary palp; III, labium; *S.m.*, submentum; *m.*, mentum; *L.*, laciniæ; *pg.*, paraglossa; *l.p.*, labial palp.

are hidden.[1] The first sternum is rudimentary, and the tenth tergum projects backwards as a plate with a deep notch in its hinder edge. A pair of many-jointed, spindle-shaped *cerci anales*, which may represent limbs, are attached under this plate, and below it is the anus, between two *podical plates*, which may represent the tergum of an eleventh segment. In the female the seventh sternum is

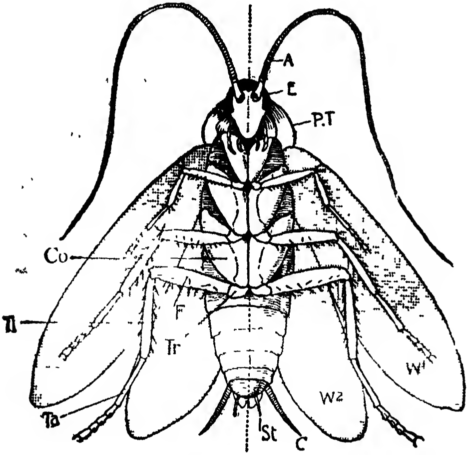


FIG. 143.—The ventral aspect of a male cockroach with the wings extended. An imaginary median line has been inserted.—From Thomson.

A., Antennæ; *C.*, cercus; *Co.*, coxa, the breadth of which makes it look, in its present position, like a ventral plate on the body; *E.*, eye; *F.*, femur; *P.T.*, prothorax; *St.*, style; *Ta.*, tarsus; *Ti.*, tibia; *Tr.*, trochanter; *W^1.*, first pair of wings; *W^2.*, second pair of wings.

produced backwards into a large boat-shaped process, which forms the floor of a *genital pouch*, and in the male the ninth sternum bears a pair of slender, unjointed *styles*. The genital opening is placed below the anus and is surrounded by a complicated set of processes known as *gonapophyses*.

The alimentary canal has long, ectodermal fore- and hind-

[1] In the male *P. orientalis* portions of the eighth and ninth terga remain uncovered.

Alimentary System.

guts, lined with cuticle as in the crayfish. The fore-gut comprises (i) the mouth, with a tongue-like ridge and the opening of the duct of the salivary glands, (ii) the narrow gullet, lying in the neck, (iii) the swollen crop, (iv) the proventriculus or gizzard, which has muscular walls and contains six hard, cuticular teeth and some pads covered with bristles which form a strainer. The mid-gut or mesenteron, lined by soft endoderm, is short and narrow and bears at its beginning seven or eight club-shaped *hepatic cæca*, which secrete a digestive fluid. The gizzard projects funnel-wise into the mid-gut. The hind-gut is coiled and divided into a narrow ileum, a wider colon, and a still wider rectum, which has six internal ridges. A pair of diffuse salivary glands lie on each side of the gut, and between each pair lies a salivary bladder or receptacle. The ducts of the two glands of each side join; the ducts of the two sides then unite to form a median duct, and this is joined by another median duct formed by the union of the ducts of the receptacles. The common duct opens into the floor of the mouth between the tongue and the lower lip. At the beginning of the hind-gut a number of long, fine *Malpighian tubules* are attached. They have an excretory function, and their lumina often contain uric acid which has been shed out by the glandular epithelium which lines them.

Respiratory Organs.

The respiratory system consists of branching tubes or *tracheæ*, with a spirally thickened, chitinous lining, which arise from ten pairs of openings or *stigmata* at the sides of the body. There are two large stigmata on each side of the thorax, one between prothorax and mesothorax, one between mesothorax and metathorax, and in each of the first eight abdominal segments a stigma is placed on each side between the tergum and the sternum. Air is pumped in and out by contraction and expansion of the abdomen, and is carried to the tissues by the fine branches of the tracheal system.

Blood Vessels.

The direct supply of air to the tissues is no doubt the reason for the simple condition of the blood-vascular system, which consists of a long heart, lying along the mid-dorsal line of the abdomen and thorax, an anterior aorta, and a system of ill-defined

sinuses. The heart is divided into thirteen chambers corresponding to the segments, and each chamber communicates by a pair of ostia at its sides with a pericardial

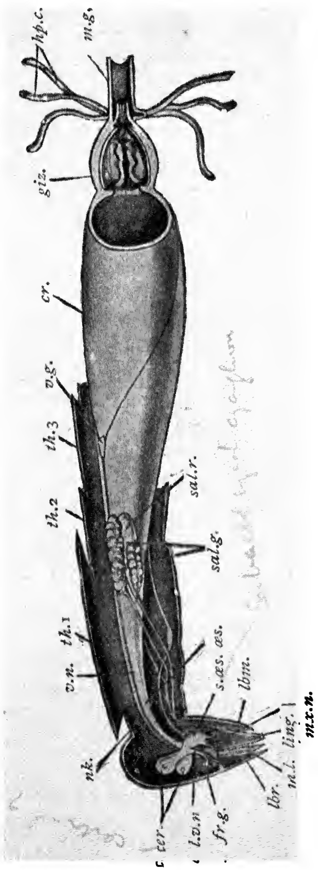


FIG. 144.—A semi-diagrammatic drawing of the head and thorax of a cockroach, dissected from the left side.

cer., Cerebral ganglion; *cr.*, crop; *fr.g.*, frontal ganglion; *giz.*, gizzard; *hp.c.*, hepatic cæca; *l.v.n.*, left visceral nerve leaving the brain; *lbm.*, labium; *ling.*, tongue; *lbr.*, labrum; *m.g.*, mesenteron; *md.*, mandible; *mx.n.*, maxillary nerve; *nk.*, neck; *œs.*, œsophagus; *s.œs.*, subœsophageal ganglion; *sal.g.*, salivary gland; *sal.r.*, salivary receptacle; *th.1*, *th.2*, *th.3*, segments of the thorax; *v.g.*, visceral ganglion; *v.n.*, visceral nerve.

space, into which blood is returned from the perivisceral cavity through openings in its floor. Paired, triangular *alary muscles*, whose outer ends are attached to the terga, move the pericardial floor, and thus cause the flow of blood

from the perivisceral cavity in the pericardial. The perivisceral and pericardial spaces contain a white tissue known as the *fatty body*, which appears, among other functions, to play some part in the formation of uric acid.

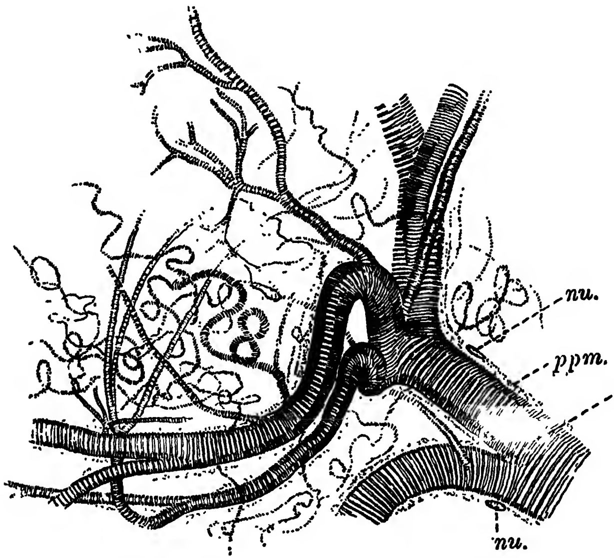


FIG. 145.—A portion of the tracheal tissue of a cockroach, highly magnified. Only parts of the tubes are in focus.

cu., Cuticular lining with spiral thickening; *nu.*, nuclei of the protoplasmic layer; *ppm.*, protoplasmic layer continuous with the epidermis ("hypodermis") of the surface of the body.

Nervous System and Sense Organs. The nervous system is on the same general plan as that of the crayfish. It comprises a pair of supra-œsophageal ganglia, which receive optic and antennary nerves, a pair of short, wide circumœsophageal commissures, a subœsophageal ganglion, and a double ventral cord with a ganglion in each of the first nine segments behind the head. The

alimentary canal is supplied by a visceral nervous system which receives nerves from the circumœsophageal commissures and the brain. Its principal ganglion lies on the upper side of the crop. The sense organs include the large compound eyes, which ~~resemble those of the~~ crayfish in structure, the antennæ, which are tactile and olfactory, the maxillæ, which are said to possess the sense of taste, the tactile anal cerci, various sensory bristles, and possibly a pair of oval, white patches on the head, above the bases of the antennæ, known as the *fenestræ*.

Organs of Reproduction.

The sexes are separate. The testes are small, paired organs, embedded in the fatty body below the fifth and sixth abdominal terga. In the adult they are no longer functional. Two vasa deferentia lead backwards and downwards from them to the seminal vesicles, which are beset with short finger-like processes and lie side by side to form the so-called *mushroom-shaped gland*. The seminal vesicles join behind to form a muscular tube, the *ductus ejaculatorius*, which opens by a medium pore between the ninth and tenth abdominal sterna. A gland of doubtful function, known as the *conglobate gland*, lies below the ductus ejaculatorius and opens with it. The ovaries are paired organs in the hinder part of the abdomen, each consisting of eight tubes, which show swellings corresponding to a row of ova. There is a single, short, wide oviduct which opens on the eighth abdominal sternum. On the ninth sternum a pair of branched *colleterial glands* pour out by two openings a secretion which forms the egg-cases. There is an unequal pair of spermathecæ, which open between the eighth and

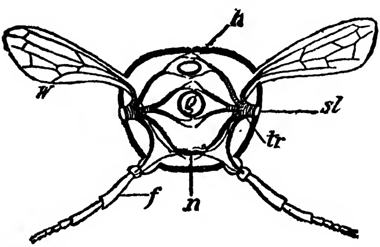


FIG. 146.—A diagram of a transverse section of an insect.—After Packard.

f., Femur of leg; *g.*, gut; *h.*, heart; *n.*, nerve-cord; *st.*, stigma; *tr.*, trachea; *w.* wing.

ninth abdominal sterna. The eggs are laid in cases, each of which contains sixteen ova and some spermatozoa from the spermathecæ. The young are like the adults, save

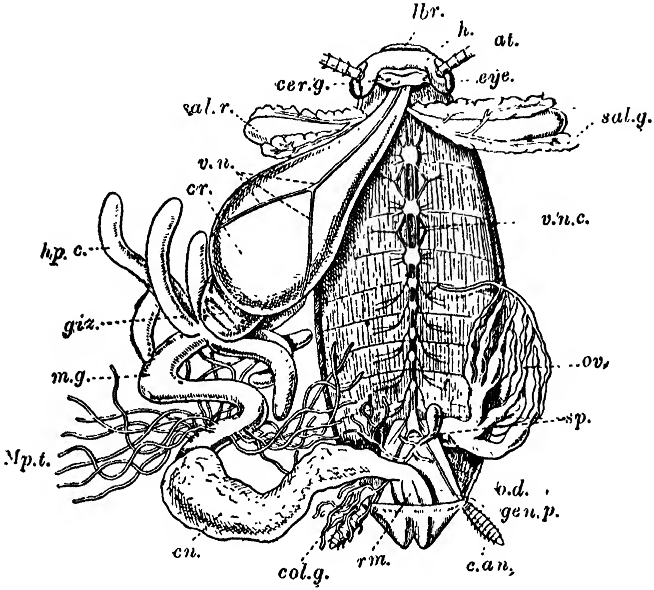


FIG. 147.—A female cockroach, dissected from above.—From Shipley and Macbride.

at., Antenna; *c.an.*, anal cerci; *cer.g.*, cerebral ganglia; *cn.*, colon; *col.g.*, colleterial gland; *cr.*, crop; *eye*; *gen.p.*, genital pouch; *giz.*, gizzard; *h.*, head; *hp.c.*, hepatic cæca; *lbr.*, labrum; *m.g.*, mesenteron; *Mp.t.*, Malpighian tubes; *od.*, oviduct; *ov*, ovary; *rm.*, rectum; *sal.g.*, salivary glands; *sal.r.*, salivary receptacle; *sp.*, spermathecæ; *v.n.*, visceral nerves; *v.n.c.*, ventral nerve cord.

for the absence of the wings, which appear after several moults. Thus the metamorphosis found in so many insects is practically absent.

CHAPTER XIII

THE DOGFISH

Habits.

VARIOUS species of the small sharks known as Dogfish are found in British waters. One of the commonest of them is the Lesser Spotted Dogfish or Rough Hound, *Scyllium canicula*. Like other dogfish, it justifies its name by travelling in packs and hunting by smell. It lives usually near the sea bottom, and feeds largely upon crabs, hermit crabs, and other crustaceans, though it also often devours shell-fish, or small fishes, and will indeed take most kinds of animal food. It is very voracious and is a nuisance to fishermen by taking the bait meant for its betters. Its flesh is not unfit for food, though coarse, but it is not eaten to any great extent.

External Features.

The length of a well-grown rough hound is about two feet. Its slender, sinister-looking body tapers from before backwards, and, though it shows no sudden differences in size, there may be recognised in it a head, trunk, and tail, the hinder limit of the former being marked roughly by an opening behind the eye known as the spiracle, and that of the trunk by the vent. The head is flat, and has a blunt-pointed snout, a wide, crescentic mouth on the lower side, a pair of round nostrils in front of the mouth and connected with it by *oronasal grooves*, and at the sides two slit-like eyes. Immediately behind each eye is a small, round opening, the *spiracle*, while farther back and more towards the ventral side is a row of slits which are the *gill slits or gill clefts*. The spiracle and the gill clefts open internally into the pharynx. Behind the head the body gradually changes its shape, becoming flattened from side to side instead of from above

downwards. The vent or opening of the cloaca lies in a deep longitudinal groove of the belly, just before the middle of the body. Into the same groove there opens at each side one of the *abdominal pores*, which lead from the body cavity. There are two pairs of fins and four unpaired fins. The *fore or pectoral fins*, corresponding to the arms of the frog, are a pair of flat, triangular organs attached by one angle to the sides of the ventral surface not far behind the head. The *hinder or pelvic fins* are smaller and narrower structures of somewhat the same shape, attached one on each side of the middle line of the belly in front of the vent. In the male, their inner edges are fused and there projects backwards from the under surface of each a rod, grooved along its inner side, known as a *clasper*. The unpaired fins are median structures in the tail. Two, known as the anterior and posterior *dorsal fins*, are on the back, one, the *ventral fin*, is on the under side, and another, the *caudal fin*, surrounds the end of the tail. This fin has two lobes, and the axis of the tail is turned upwards and passes into the upper lobe.

General Internal Features.

Certain generalisations which we have made in the course of the previous chapters enable us to state in a few words a good deal of information about the anatomy of the dogfish. A

FIG. 148.—The Rough Hound.

Note mouth, eye, spiracle, lateral line, gill clefts, pectoral and pelvic fins, dorsal fins, caudal fin, ventral fin between caudal and pelvic fins.

c.f., Upper lobe of caudal fin; *c.f'.*, lower lobe of the same; *pl.f.*, right pelvic fin.

dogfish is a metazoan animal. It is triploblastic and cœlomate. It has a large, cœlomic perivisceral cavity and a closed circulation. It is bilaterally symmetrical. It is segmented, though the primary segmentation is best seen in the early stages of development and is represented in the adult only by the arrangement of the muscles of the body-wall, the segmentation which is found in the backbone and nervous system arising later. It is chordate (p. 306).

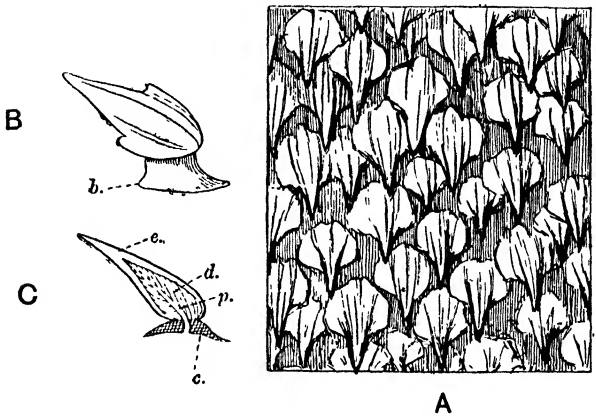


FIG. 149.—Placoid scales.

A, A portion of the skin of the rough hound as seen under a hand lens; *B*, a single scale removed from the skin; *C*, the same in section (diagrammatic).

b., Base of the scale; *c.*, the same in section; *d.*, dentine; *e.*, enamel; *p.*, pulp cavity.

Lastly, like the frog, it is a *backboned or vertebrate* animal. This term implies more than the possession of a backbone. The *Vertebrata* are a large group of animals which have in common, besides the features we have just mentioned, the following: (1) they possess an internal skeleton of bone or cartilage, part of which forms a skull and backbone; (2) their central nervous system, which is hollow and dorsal like that of all chordate animals, consists of a spinal cord and a complicated brain; (3) the gill clefts, which they all possess during some period of development, are few and

do not open into an atrium (p. 303); (4) they have a heart, which lies below the gut; (5) most, though not all of them, possess two pairs of limbs, and none has more.

Skin. Upon the back and sides of the rough hound the skin is of a grey-brown colour with small spots of darker brown; upon the belly it is whitish. It feels smooth to the hand if it be stroked from head to tail, but rough if it be stroked in the opposite direction. This is due to the presence of *scales*, which are not flat like those of most fishes, but bear minute spines directed backwards.

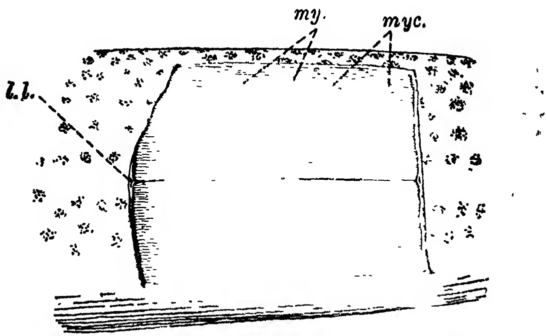


FIG. 150.—Part of the tail of a dogfish seen from the left side, with a piece of the skin removed.

l.l., Tube the lateral line; *myc.*, myocommata or septa of connective tissue; *mym.*, myomeres.

Such scales are said to be *placoid.* Each consists of a calcified basal plate embedded in the dermis, and a spine which is composed of dentine covered with enamel. A pulp cavity, containing highly vascular connective tissue, passes through the base into the spine. It will be seen that the general features of such a scale resemble those of the tooth of a frog. In fact the teeth of the dogfish, though they are larger, have the structures of the scales, and we must regard teeth as modified scales.

The muscles of the body-wall are for the most part segmentally arranged, each muscle-segment being known as a myomere. The myomeres do not lie straight, but

each is bent four times, so that it runs a zigzag course from the middle of the back to that of the belly.

Muscles and Movements.

In the muscles of the head, throat, and fins the segmental arrangement is not apparent. The myomeres are separated by partitions of connective tissue (myocommata), between which their fibres run longitudinally. By the action of these muscles, especially in the powerful tail, which is more than half the length of the body, the animal is driven through the water, the tail working from side to side with a twisting motion, as an oar may be used from the stern of a boat to propel it. The upturned position of the axis of the tail helps to keep the snout upon the ground as the fish "noses" about for its food. The dorsal and ventral fins act like the keel of a boat in keeping the body upright, and the paired fins help in balancing and are used in steering upwards and downwards.

Skeleton: General Features.

The scales of the dogfish constitute a part of the skeleton known as the *exoskeleton*, which in the frog is represented only by the teeth. The *endoskeleton* of the dogfish corresponds to that of the frog in its main outlines, but differs from it in some important respects. (1) It is wholly cartilaginous, like that of the tadpole, containing nothing which corresponds either to the membrane bones or to the cartilage bones of the frog, though in places the cartilage is calcified. (2) The axial skeleton is traversed below the central nervous system by a peculiar rod, the notochord, which consists of large, vacuolated cells with stout walls, and is derived from the endoderm in the course of development. This is present in the tadpole, but in the adult frog is represented only by pads of tissue between the centra of the vertebræ. (3) There are no structures which represent any part of the sternum. (4) In correspondence with the difference in the shape of the limbs, their skeleton differs entirely in the two animals. (5) Unlike that of the tadpole, the median fins are supported by rays.

Backbone.

The backbone consists of about 130 vertebræ, in each of which the centrum is pierced from end to end by a canal for the notochord. This canal is narrower in the middle of the vertebra, so that the notochord is constricted, and after its removal

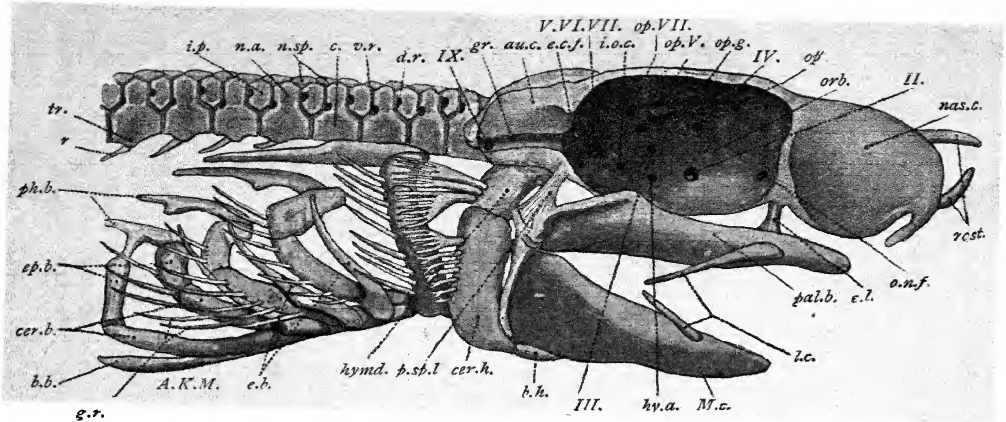


Fig. 151.—Skull and part of the backbone of a dogfish, seen from the right side. The skeleton of the visceral arches has been pulled a little downwards.

au.c., Auditory capsule; *b.b.*, basibranchial cartilage; *b.h.*, basihyal cartilage; *c.*, centrum; *cer.h.*, ceratohyal cartilage; *cer.b.*, ceratobranchial cartilages; *d.r.*,*v.r.*, foramina for the dorsal and ventral roots of a spinal nerve; *e.b.*, extrabranchial cartilages; *e.c.f.*, external carotid foramen; *ep.b.*, epibranchial cartilages; *e.l.*, ethmopalatine ligament; *gr.*, groove for vein which connects orbital and anterior cardinal sinuses; *g.r.*, gill rays; *hy.a.*, foramen for hyoidean artery; *hymd.*, hyomandibular cartilage; *i.o c.*, interorbital canal; *i.p.*, intercalary plate; *M.c.*, Meckel's cartilage; *l.c.*, labial cartilages; *nas.c.*, nasal capsule; *n.a.*, neural arch; *n.sp.*, neural spine; *o.n.f.*, orbitonasal foramen; *op.V.*, *op.VII.*, foramina for ophthalmic branches of fifth and seventh nerves; *op'.*, foramen through which combined ophthalmic nerves pass from the orbit to the snout; *op.g.*, grooves for *ob.V.*, *VII.*; *orb.*, orbit; *p.sp.l.*, postspiracular ligament; *pal.b*, palatine bar; *ph.b.*, pharyngobranchial cartilages; *r.*, rib; *rost.*, rostrum; *tr.*, ventrilateral (so-called transverse) process.

Other views of these structures are given in Fig. 152.

the centrum appears as a biconcave disc. On each side the centrum bears a pair of *ventrilateral processes*.[1] In the trunk region these are directed outwards and bear short *ribs*, which lie beneath the muscles of the back; in the hinder part of the body the processes are directed downwards and are known as *hæmal arches*, enclosing a *hæmal canal*, in which lie the caudal artery and vein. Towards the hinder end of the tail they fuse at their ends and bear a median *hæmal spine*. Between the neural arches of successive vertebræ are wide gaps which are closed by *intercalary pieces*. The *neural spines* are a series of flat median pieces of cartilage, twice as numerous as the vertebræ, which fill the gaps between the tops of the neural arches and intercalary pieces and roof in the vertebral canal

Skull. The skull consists, like that of the frog, of a cranium which contains the brain, with a pair of nasal capsules in front, a pair of auditory capsules one at each side of the hinder end, and a visceral skeleton below. The nasal capsules are large, thin-walled structures, continuous with the cranium, widely open below, and separated by the *cartilaginous internasal septum or mesethmoid cartilage*. Three slender processes, one from the front wall of each capsule and one from the mesethmoid cartilage, project into the snout and are together known as the *rostrum*. At the junction of the cranium and the nasal capsules the roof of the skull shows a large gap, the *anterior fontanelle*. From the sides of the cranium large *supra- and suborbital ridges* project to protect the orbit above and below. On the auditory capsules, which are continuous with the cranium, ridges mark the position of the semicircular canals. A median depression on the roof between the auditory capsules communicates on each side with a canal, carrying the *aqueductus vestibuli*, which leads to the internal ear and puts the endolymph into communication with the sea water through a small opening. There is no ear drum. At the hinder end, between two occipital condyles, may be seen the notochord, which passes into the floor of the cranium for some distance. Numerous openings pierce the wall of the

[1] These are often called transverse processes, but they do not correspond with the transverse processes of the frog, which belong to the neural arches.

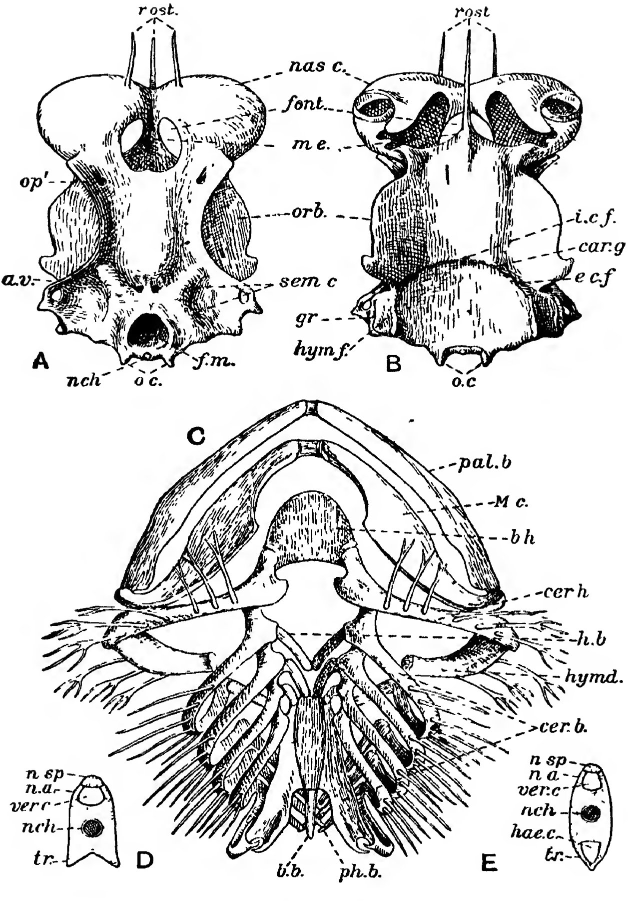


FIG. 152.—Parts of the skeleton of the dogfish.

A, The skull, from above; *B*, the same, from below; *C*, skeleton of visceral arches, not including the labial or extrabranchial cartilages; *D*, section of a trunk vertebra; *E*, section of a tail vertebra.

a.v., Opening of tube from inner ear; ***b.b.***, ***b.h.***, ***cer.b.***, ***cer.h.***, ***e.c.f.***, ***gr.***, ***hymd.***, ***M.c.***, ***n.a.***, ***n.sp.***, ***nas.c.***, ***orb.***, ***op'.***, ***pal.b.***, ***ph.b.***, ***rost.***, ***tr.***, as in Fig. 151; ***car.g.***, groove for carotid artery; ***f.m.***, foramen magnum; ***font.***, fontanelle; ***h.b.***, hypobranchial cartilage; ***hae.c.***, hæmal canal; ***hym.f.***, facet for hyomandibular cartilage; ***i.c.f.***, foramen for internal carotid arteries; ***m.e.***, mesethmoid cartilage; ***nch.***, notochord; ***o.c.***, occipital condyles; ***sem.c.***, semicircular canals; ***ver.c.***, vertebral foramen.

cranium. (1) On the roof lies the anterior fontanelle which we have already mentioned. (2) At the front end two large foramina put the cranial cavity in continuity with those of the nasal capsules. Through these the olfactory nerves pass from the surface of each olfactory lobe of the brain into the olfactory organ. (3) On each side wall numerous openings allow the passage of nerves and blood vessels to and from the orbit. The relative sizes and positions of these are seen in Fig. 151. (4) Just behind the auditory capsules, at the bottom of a deep pit, is the foramen for the ninth nerve, and on each side of the occipital condyles is a foramen for the passage of the tenth nerve. (5) On the under side there may be seen two shallow grooves, along which the internal carotid arteries run. Where these meet there is a small opening, through which the two arteries enter the cranium. At the outer ends of the grooves are the openings through which the external carotid arteries pass from the roof of the mouth to the orbits. (6) At the hinder end of the skull is the large foramen magnum. The *visceral skeleton* is a series of seven arches, each consisting of several pieces, which lie at the sides of the mouth. The first of these is the *mandibular arch*, which forms the skeleton of the jaws. Each half of the *upper jaw-bar or palato-pterygo-quadrate cartilage* is a rod which meets its fellow in front of the mouth and is there joined to it by a ligament. It is attached to the cranium in front of the orbit by the *ethmopalatine ligament* and behind to the auditory capsule by a *postspiracular ligament.* Each half of the lower jaw is formed by Meckel's cartilage, which is a wide, flat bar, tapering forwards to a point, where it is joined with its fellow by a ligament. It articulates behind with the palato-pterygo-quadrate cartilage and is joined by ligament to the hyomandibular cartilage which forms its principal attachment to the skull. The second or *hyoid arch* consists of two pieces, an upper *hyomandibular cartilage*, which is a short, stout rod articulated with a large facet on the side of the auditory capsule, and a longer, more slender, *ceratohyal cartilage*, which passes forwards and inwards from the hyomandibular to join a median plate, the *basihyal cartilage*, in the floor of the mouth. The remaining five arches are the *branchial arches.*

Each branchial arch contains above a flat, pointed *pharyngobranchial* which, starting beside the backbone, slopes forwards to join an *epibranchial* that lies at the side of the pharynx in a line with the hyomandibular cartilage. From the lower end of this the *ceratobranchial* runs forwards and inwards parallel with the ceratohyal and mandibular cartilages. The first four ceratobranchials are connected with *hypobranchials* in the floor of the pharynx. The first hypobranchial is small and joins the first ceratobranchial with the basihyal;

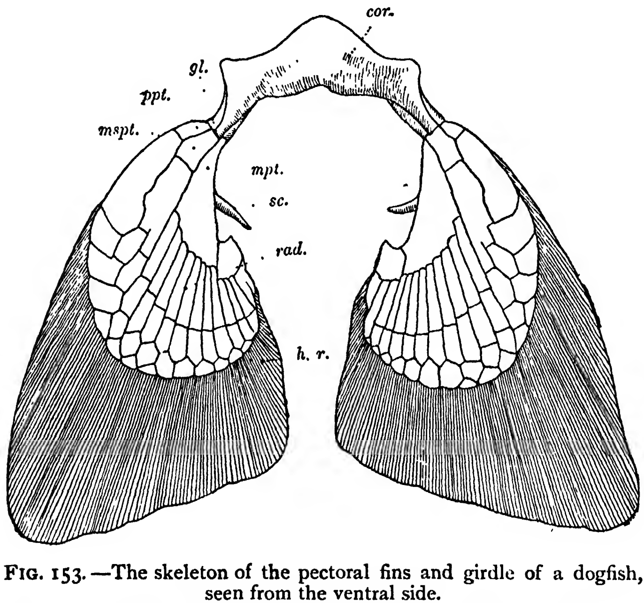


FIG. 153.—The skeleton of the pectoral fins and girdle of a dogfish, seen from the ventral side.

cor., Coracoid region; *gl.*, glenoid surface; *h.r.*, horny rays; *mpt.*, metapterygium; *mspt.*, mesopterygium; *ppt.*, propterygium; *rad.*, cartilaginous rays; *sc.*, scapula.

the three hinder are larger and directed backwards and inwards. The last two pairs of hypobranchials and the fifth ceratobranchials join a median *basibranchial plate.* The epibranchial, ceratobranchial, hyomandibular, and ceratohyal cartilages bear *gill rays* along their hinder borders. Outside the upper and lower jaws lie a pair of *labial cartilages*, and along the outer sides of the second, third, and fourth ceratobranchials are *extrabranchials.*

The median fins are supported by a skeleton consisting of several series of rays. The series nearest the body are cartilaginous rods known

as *basalia* and are attached to the neural and hæmal spines. They are succeeded by a similar series known as *radialia*, and these by two rows of small, polygonal plates of cartilage which support a final series of horny rays or *actinotrichia*. In the caudal fin the cartilaginous rays are not distinct from the neural and hæmal spines.

Limbs.

The limbs are anchored into the body by girdles which correspond to those of the frog. The pectoral girdle consists of two curved pieces of cartilage, at the sides of the body, of which the lower ends are fused in the mid-ventral line. To the hinder sides of these pieces are articulated the fins. The surface of articulation is the *glenoid facet*, the portion of the girdle above the facet being the *scapular region* and that below the *coracoid*. The scapula is rod-like; the coracoid is broad and flat and supports the floor of the pericardium. The pectoral fin articulates with its girdle by three basal cartilages, the *pro-*, *meso-*, *and metapterygia*, of which the former is the anterior and smallest, the metapterygium the hinder and largest. Along the outer borders of these pieces are set a series of *radialia*. The pro- and mesopterygia each bear one stout ray, the metapterygium several, which are slender. To the end of these, smaller, polygonal pieces are attached, and to

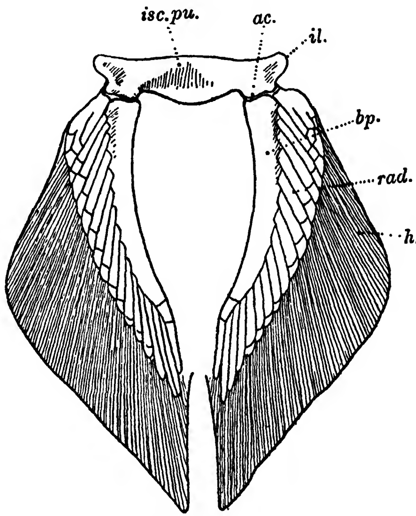


FIG. 154.—The skeleton of the pelvic fins and girdle of a female dogfish

ac., Acetabular surface; *bp.*, basipterygium; *h.r.*, horny rays; *il.*, iliac process; *isc.pu.*, ischio-pubic region; *rad.*, cartilaginous rays.

them in turn horny *actinotrichia.* The pelvic girdle is a stout, straight bar of cartilage, placed athwart the belly and bearing a blunt knob at each end. The main part of the bar is the *ischiopubic region*, the knobs are the *iliac processes*, and the fins articulate with an *acetabular facet* upon the hinder border at the base of the iliac processes. The fin has a long, inwardly-curved *basipterygium*, bearing a row of radialia along its outer side. In the male it also bears a long piece of cartilage which supports the clasper.

Cœlom and Alimentary System.

The perivisceral cavity lies wholly in the trunk, and is divided into two parts, the small pericardium just in front of the pectoral fins, and the large pleuro-peritoneal cavity behind it, between the two pairs of fins. The two cavities are divided by a membranous septum, but a narrow passage, the *pericardio-peritoneal canal*, leads from one to the other below the œsophagus. As in the frog, the pleuro-peritoneal cavity contains, among other organs, the whole of the alimentary canal with the exception of the mouth and pharynx. The gape of the mouth is edged with several rows of teeth, which, as we have seen, are simply enlarged scales. These lie in a part of the skin which passes over the jaw and is tucked into a groove within it. They are not in any way attached to the jaw. As they wear away, they are replaced by new rows which are constantly being formed in the groove and carried up over the edge of the jaw by the growth of the skin. The pharynx is only distinguished from the mouth by possessing the inner openings of the spiracle and gill clefts. These are placed between the arches of the visceral skeleton, the first gill cleft lying between the hyoid and first branchial arches. The clefts do not pass straight outwards through the wall of the throat, but the outer opening of each is at some distance behind the inner, so that the cleft is a pouch which slants backwards and outwards from the pharynx to the exterior. The pouches are spacious cavities, being deep, and considerably taller than their openings at either end, though the inner opening is larger than the outer. On each wall of the pouch lie a number of folds which constitute a *gill.* These are highly vascular, and in fresh specimens have consequently a bright red colour. There is

a gill on each side of each cleft except the last, which has no gill on the hinder side. The spiracle is a small cleft of the same series as the gill cleft, and bears on its front side a vestige

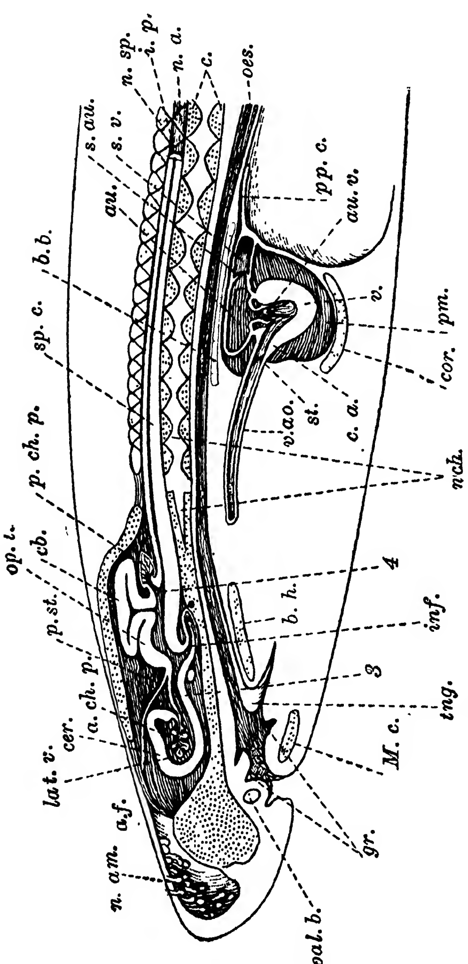
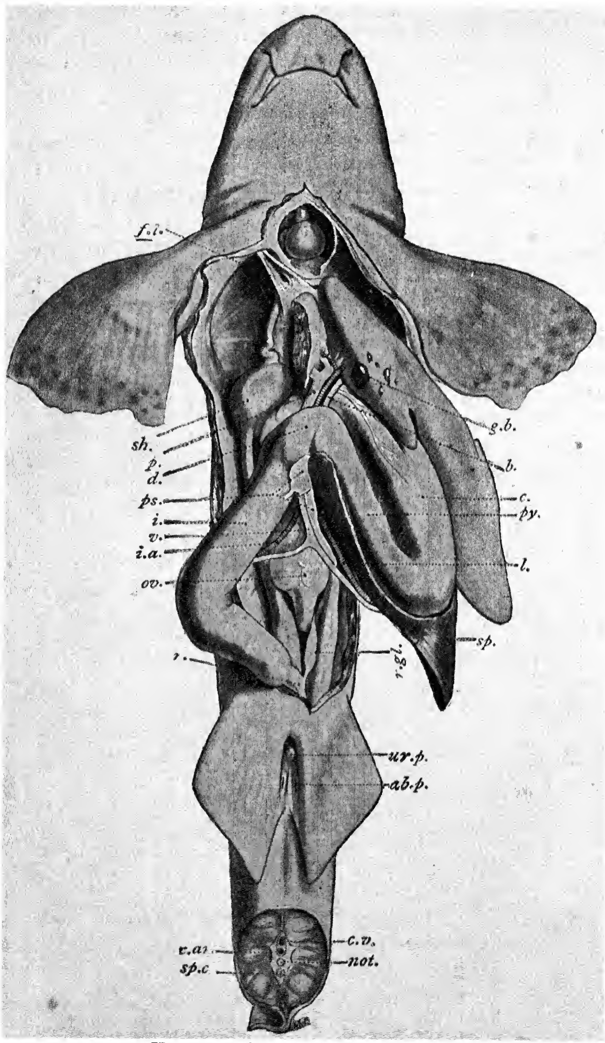


FIG. 155.—A semi-diagrammatic drawing of a longitudinal section through a dogfish, passing slightly to the right of the middle line.

a.ch.p., Anterior choroid plexus; *a.f.*, anterior fontanelle; *au.*, auricle; *au.v.*, auriculo-ventricular opening and valve; *b.b.*, basibranchial cartilage; *b.h.*, basihyal cartilage; *c.*, centrum; *c.a.*, conus arteriosus; *cb.*, cerebellum; *cer.*, cerebrum; *cor.*, coracoid region of the pectoral girdle; *gr.*, grooves in which the teeth are formed; *i.p.*, intercalary plate; *inf.*, infundibulum; *lat.v.*, lateral ventricle; *M.c.*, Meckel's cartilage; *n.a.*, neural arch; *n.am.*, ampullary sense organs; *n.sp.*, neural spine; *nch.*, notochord; *oes.*, œsophagus; *op.l.*, optic lobe; *p.ch.p.*, posterior choroid plexus; *p.st.*, pineal stalk; *pal.b.*, palatine bar; *pm.*, pericardium; *pp.c.*, pericardio-peritoneal canal; *s.au.*, sinu-auricular opening; *s.v.*, sinus venosus; *sp.c.*, spinal cord; *st.*, semilunar valves; *tng.*, tongue; *v.*, ventricle; *v.ao.*, ventral aorta; 3, third ventricle; 4, fourth ventricle



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of a gill, known as a *pseudobranch.* The regions between the clefts, and those immediately in front of the first cleft (the spiracle) and behind the last, are known as *visceral arches*, and named, in order, mandibular, hyoid, and first to fifth branchial. Each contains a skeletal arch, arteries, and a nerve. The spiracle separates the mandibular and hyoid arches. The gills are respiratory organs. In life the fish is continually taking in water at the mouth and passing it out over the gills and through the clefts by a munching action of the lower jaw. From the pharynx the narrower œsophagus leads back through the cœlom to the stomach. This is sharply divided into a cardiac and a pyloric part. The former is a sac, in shape not unlike the stomach of the frog; near its hinder end on the right side arises the narrow tubular pyloric division, which runs forwards beside the cardiac. At its front end a slight constriction marks the presence of the pyloric sphincter and divides it from the intestine. The main part of this is a long, wide sac, known as the ileum, which passes backwards towards the cloaca and has its internal surface increased by a spiral fold of the mucous membrane known as the *spiral valve.* Between this region and the pyloric sphincter lies a short, somewhat narrower region called the duodenum or *bursa entiana*, which is without a spiral valve and receives the ducts of the liver and pancreas. At its hinder end the ileum

FIG. 156.—A female dogfish in which the abdominal and pericardial cavities have been opened from the ventral side, and the viscera somewhat displaced. The pericardium has been opened slightly to the left of the middle line, and the right lobe of the liver has been cut away.

ab.p., Abdominal pores; *b.*, bile duct; *c.*, cardiac limb of stomach: *c.ar.*, caudal artery; *c.v.*, caudal vein; *d.*, bursa entiana; *f.l.*, falciform ligament, with the internal opening of oviducts; *g.b.*, portion of gall bladder appearing on surface of left lobe of liver in which it is embedded; *i.*, intestine; *i.a.*, intestinal branch of anterior mesenteric artery; *l.*, lienogastric artery; *not.*, notochord; *ov.*, ovary; *p.*, portal vein lying beside hepatic artery; *ps.*, pancreas with duct opening into intestine, *py.*, pyloric limb of stomach; *r.*, rectum, between hinder ends of oviducts, with rectal gland (*r.gl.*) attached to its dorsal side; *sh.*, right shell gland on course of right oviduct; *sp.*, spleen; *sp.c.*, spinal cord; *ur.p.*, urinary papilla; *v.*, branch of portal vein formed by junction of intestinal and splenic veins.

Besides the above, note—nostrils; oronasal grooves; mouth; pectoral and pelvic fins; pericardial and abdominal cavities; heart, consisting of sinus venosus (behind), ventricle, auricle (showing at sides of ventricle), and conus; cloaca, and transverse section of tail, showing at the sides the myomeres, above the anterior dorsal fin, and in the middle the cartilage of the backbone enclosing spinal cord, notochord, and blood vessels.

narrows and loses its spiral valve, thus becoming the rectum, this in turn ending in the wider cloaca, which receives the urinary and generative ducts and opens by the vent. There is no bladder. The liver is a very large organ, consisting of long right and left lobes united in front and slung by the *falciform ligament* from the anterior wall of the peritoneal cavity. The gall bladder is embedded in the front part of the left lobe of the liver, but usually a part of it shows upon the surface. From it the bile duct runs backwards to open into the intestine, lying in the membrane or *omentum* which carries the hepatic artery and portal vein. The pancreas lies between the stomach and intestine; it is long and narrow and has in front a rounded ventral lobe, from which its duct passes to the ventral side of the intestine. The *rectal gland* is a small, cylindrical structure which opens into the dorsal side of the rectum by a duct. The spleen must be mentioned here, although it has no connection with the alimentary canal. It is attached by membrane to the hinder end of the stomach as a triangular lobe with a forward prolongation along the right side of the pyloric division.]

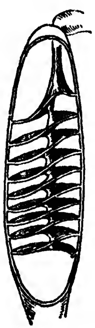


FIG. 157.—Diagram of spiral valve. —After T. J. Parker.

Excretory and Generative Organs.

The kidneys of the dogfish are relatively longer than those of the frog, but otherwise resemble them in position and structure, lying above the abdominal cavity just outside the peritoneum, and consisting of numerous tubules, whose nephrostomes in this case remain open. In the early stages of development the tubules correspond with the muscle segments, but later they become more numerous. The kidneys have three sections, known as the *fore, mid, and hind kidneys, or pro-, meso-, and metanephros*,[1] but the first

[1] The permanent meso- and metanephros of the dogfish correspond only roughly with the regions to which the same names are given in the embryos of higher vertebrates (see pp. 285, 287). Together they are called the *opisthonephros.*

of these is rudimentary and disappears early in development. The mesonephros is a long, narrow organ, which in the adult female is reduced to a mere vestige and can only be found by removing the peritoneum, but in the male is better developed and, with its duct, makes a ridge along the body cavity. Its collecting tubules open directly into the Wolffian duct. The metanephros is a larger organ which forms a cushion-like swelling and is the principal excretory organ in both sexes; its collecting tubules, as will presently be explained, discharge into ducts of their own, which in the male do not enter the Wolffian duct. It is not seen in the frog, where the whole kidney is mesonephric. A duct,—the *mesonephric or*

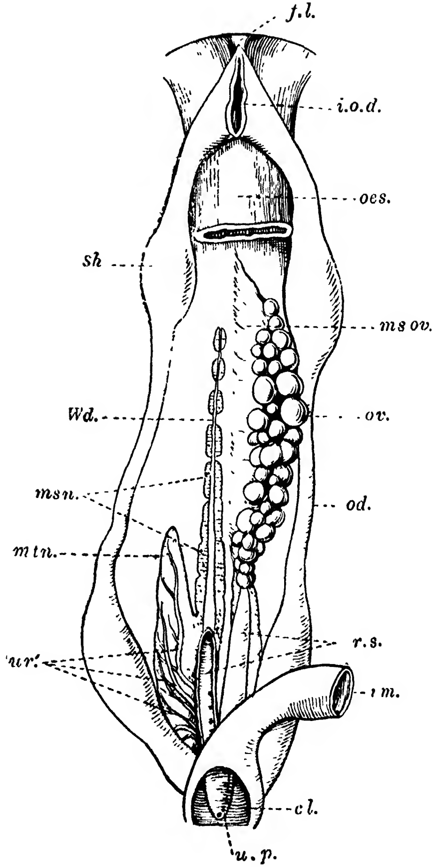


FIG. 158.—The reproductive organs of a female dogfish.

cl., Cloaca; *f.l.*, part of the "falciform ligament. *i o.d.*, internal opening of the oviducts; *msn.*, mesonephros; *msov.*, mesovarium; *mtn.*, metanephros: *o.d.*, oviduct; *oes.*, œsophagus; *ov.*, ovary; *rm.*, rectum; *sh.*, shell gland; *ur'.*, ducts of metanephros; *u.p.*, urinary papilla; *ur.s.*, urinary sinus; *W.d.*, Wolffian duct.

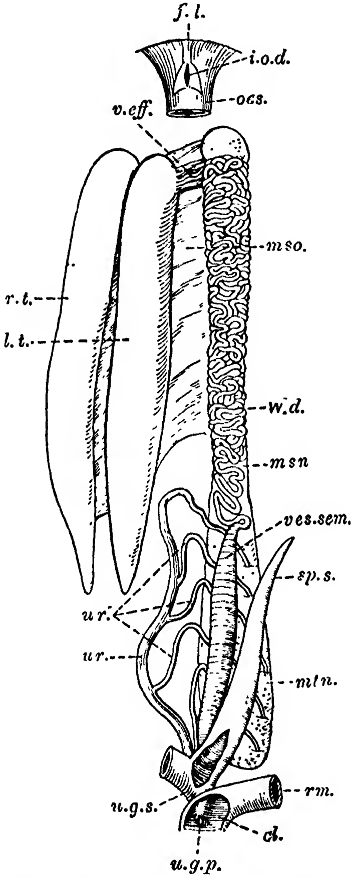


FIG. 159.—The reproductive organs of a male dogfish.

cl., Cloaca; *f.l.*, "falciform" ligament; *i.o.d.*, rudiment of the internal opening of the oviducts; *l.t.*, left testis; *msn.*, mesonephros; *mso.*, mesorchium; *mtn.*, metanephros; *oes.*, œsophagus; *r.t.*, right testis; *rm.*, rectum; *sp.s.*, sperm sac; *u.g.p.*, urinogenital papilla; *u.g.s.*, urinogenital sinus; *ur.*, ureter; *ur'.*, ducts of metanephros; *v.eff.*, vasa efferentia; *ves.sem.*, vesicula seminalis; *W.d.*, Wolffian duct or vas deferens.

Wolffian duct, — corresponding to the kidney duct of the frog, runs the whole length of the kidney, lying upon its ventral face and receiving the tubules of the mesonephros. In the female it is straight and its hinder end is widened to form a *urinary sinus*, which joins its fellow to open into the cloaca upon a median *urinary papilla*; in the male it is coiled and serves, as in the frog, for the vas deferens, its swollen hinder part being a vesicula seminalis. The tubules of each metanephros are received into five or six ducts, which in the female open into the urinary sinus of their side, but in the male join to form a *ureter* which passes backwards to open separately from the vesicula seminalis into a median *urinogenital sinus*. This has two forward horns known as the *sperm sacs*, which lie upon the ventral faces of the vesiculæ seminales, and opens behind into the cloaca by a *urinogenital papilla* behind the anus. There is a single ovary,

which probably represents that of the right side of the frog. It hangs into the body cavity and varies in size and appearance with age. The ova are in different stages of ripeness, the ripest being very large and yolky. They are shed into the body cavity and passed forwards by contractions of the abdominal walls to the front of the peritoneal space, where they enter the *internal opening of the oviducts*. The latter are large, straight tubes, one on each side of the body, attached to the dorsal wall of the cœlom. They start from a common opening in the falciform ligament, not far behind which each has a round swelling known as the *shell gland*. At the hinder end of the trunk they enter the cloaca by a common opening just behind the anus. The testes are a pair of long organs slung by membranes from the dorsal wall of the cœlom. Each communicates at its front end with the mesonephros of its side by several small vasa efferentia, the sperm passing through these into the mesonephric tubules and thence to the vas deferens or Wolffian duct, by which it is conveyed to the urinogenital sinus. A rudiment of the internal opening of the oviducts is found in the falciform ligament of the male. Sperm is passed by the aid of the claspers into the cloaca of the female and fertilisation takes place within her. The eggs are laid in flat, oblong, brown shells whose angles are prolonged into tapering tendrils, which twine round seaweeds and thus anchor the egg. Protected

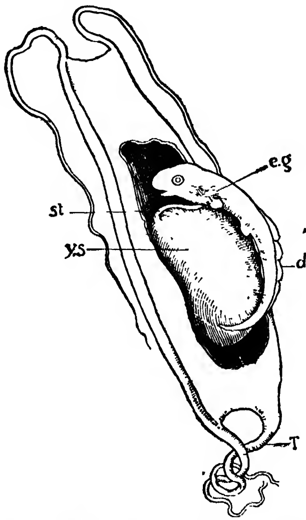


FIG. 160.—An embryo dogfish in its egg-case ("mermaid's purse") which has been cut open to show the contents.—From Thomson.

d.f., Dorsal fin fold; *e.g.*, "external" gills; *st.*, stalk of yolk-sac; *T.*, tendrils, prolongations of egg-case by means of which it is moored to seaweed; *y.s.*, yolk-sac.

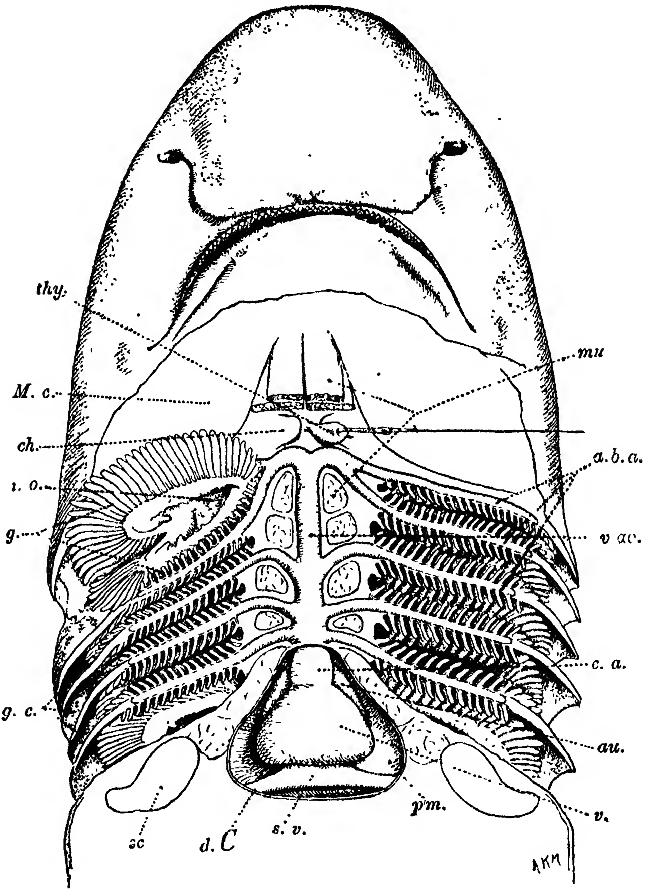


FIG. 161.—The forepart of the body of a dogfish, dissected to show the heart and ventral arterial system.

a.b.a., Afferent branchial arteries; *au.*, auricle; *c.a.*, conus arteriosus; *ch.*, ceratohyal cartilage; *d.C.*, ductus Cuvieri; *g.*, gills; *g.c.*, gill clefts; *ı.o.*, internal opening of the first gill cleft; *M.c.*, Meckel's cartilage; *mu.*, muscles from coracoid region of shoulder girdle to various parts of visceral skeleton; *pm.*, pericardium; *s.v.*, sinus venosus; *sc.*, scapula; *thy.*, thyroid gland (displaced); *v.*, ventricle; *v.ao.*, ventral aorta.

by the shell, the young dogfish develops slowly at the expense of the yolk, which comes to be contained in a sac attached to its belly. At one stage long, vascular threads project from the gill clefts of the little fish. These are the so-called external gills, but they are covered with endoderm and thus differ from the true external gills of the tadpole.

Blood Vessels: Heart. The heart of a dogfish lies in the pericardium between the hinder gill-clefts of the right and left sides. It is a median structure with muscular walls, and consists essentially of an irregular tube, bent like an **S** upwards and downwards (Fig. 155) and composed of four successive chambers. The hindermost chamber is the thin-walled sinus venosus, which is triangular as seen from below, and lies with its base against the hinder wall of the pericardium. In front of it comes the thicker walled auricle or atrium. This is also triangular, with its apex forwards, and has its hinder angles widened into pouches, but is not divided into two chambers like that of the frog. The **S** then curves downwards, as the very thick-walled, conical ventricle, which lies below and somewhat behind the auricle. From it the narrow conus arteriosus passes forwards through the front wall of the pericardium to become the ventral aorta, which is merely the foremost part of the single vessel whose thickening and twisting produces the heart behind. Thus the heart, or contractile blood-vessel, of the dogfish, like that of the frog and all other vertebrate animals, is ventral in position, whereas the principal contractile vessel of an invertebrate is generally dorsal. The heart contracts from behind forwards, and drives blood into the ventral aorta, reflux being prevented by a valve at the opening of the sinus into the auricle, another at the auriculo-ventricular opening, and two rows of semilunar or watch-pocket valves in the conus.

Arteries. The ventral aorta lies in the middle of the throat, below the pharynx and between the gill clefts, giving off *afferent branchial arteries* to the fourth, third, and second branchial arches, and ending by dividing into two vessels, each of which again forks to supply the first branchial and hyoid arches of its side. There are thus five afferent branchial arteries. These, together with the ventral aorta, form the *ventral arterial system*. The thyroid gland,

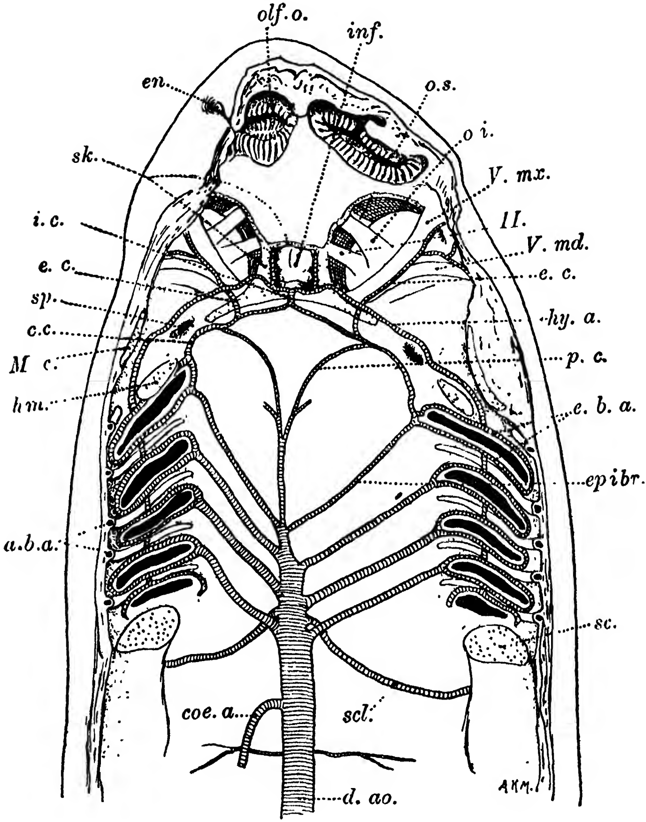


FIG. 162.—The forepart of a dogfish, dissected from the ventral side, to show the dorsal arterial system, the olfactory organs, and certain structures in the orbits. The middle part of the floor of the mouth has been removed.

a.b.a., Afferent branchial arteries; *c.c.*, common carotid artery; *coe.a.*, cœliac artery; *d.ao.*, dorsal aorta; *e.b.a.*, efferent branchial arteries; *e.c.*, external carotid; *en.*, nostril; *epibr.*, epibranchial artery; *hm.*, hyomandibular cartilage; *hy.a.*, hyoidean artery; *i.c.*, internal carotid arteries; *inf.*, infundibulum; *M.c.*, Meckel's cartilage in lower jaw; *o.i.*, inferior oblique muscle; *o.s.*, superior oblique muscle; *olf.o.*, olfactory organ; *p.c.*, posterior carotid artery; *sc.*, scapula; *scl.*, subclavian artery; *sk.*, skull; *sp.*, spiracle; *V.md.*, *V.mx.*, mandibular and maxillary branches of fifth nerve; *II.*, optic nerve.

an c n of doubtful function (p. 51) which does not belong to t vascular system, lies below the anterior end of the vent aorta as a pear-shaped body with the stalk forwards. Froı he afferent branchial arteries the blood passes into the capi ries of the gills, where it is oxygenated and gathered up i o *efferent branchial arteries.* These form a complete loop round each of the first four clefts, the loops being joinec fore and aft by short horizontal vessels at about the middle of their lengths. The last cleft, having no gill on its hinder side, has an efferent vessel on its front side only, and all the blood of this vessel passes by the horizontal

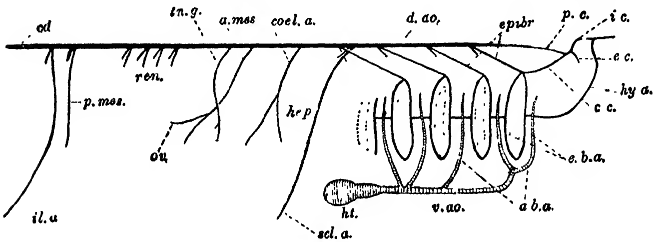


FIG. 163.—A diagram of the arterial system of a dogfish, seen from the right side.

a.b.a., Afferent branchial arteries; *a.mes.*, anterior mesenteric artery; *c.c.*, common carotid artery; *cd.*, caudal artery; *coel.a.*, cœliac artery; *d.ao.*, dorsal aorta; *e.b.a.*, efferent branchial arteries; *e.c.*, external carotid artery; *epibr.*, epibranchial arteries; *ht.*, heart; *hep.*, hepatic artery; *hy.a.*, hyoidean artery (this joins the internal carotid of the opposite side, which is not shown); *i.c.*, internal carotid artery; *il.a.*, iliac artery; *ln.g.*, lienogastric artery; *ov.*, ovarian artery; *p.c.*, posterior carotid artery; *p.mes.*, posterior mesenteric artery; *ren.*, renal arteries; *scl.a.*, subclavian artery; *v.ao.*, ventral aorta.

vessel into that of the gill in front. From the dorsal end of each of the complete loops arises a vessel known as an *epibranchial artery*, which runs backwards and inwards on the roof of the pharynx to join the median dorsal aorta opposite to its fellow of the other side. From the dorsal end of the first efferent branchial artery, just outside the origin of the first epibranchial artery, arises the common carotid artery. This runs forwards and inwards under the skull. Behind the orbit it divides into an external and an internal branch. The former immediately passes through the opening we have mentioned (p. 231) and runs forwards along the floor of the orbit to supply the upper jaw and the

snout. The internal carotid artery continues its course in the carotid groove, towards the middle line, where with its fellow it passes through the internal carotid foramen into the cranium to supply the brain. Outside the cranium yet another artery arises from the first efferent branchial vessel. This is the *hyoidean artery*, which starts in a line with the horizontal vessels which join the loops, runs forwards to the spiracle, where it supplies the pseudobranch, crosses the orbital floor, enters the cranium by a small foramen in the inner wall of the orbit, and joins the crossed internal carotid artery of the opposite side. The dorsal aorta ends in front by breaking into two small *posterior carotid arteries*, which curve outwards and join the common carotid trunks. Just before it is joined by the last pair of epibranchial vessels it gives off a pair of subclavian arteries, which pass backwards and outwards to the fore-fins. Behind the pharynx it runs backwards along the whole length of the body below the backbone, lying, in the tail, in the hæmal canal as the *caudal artery*. Besides paired vessels to the body-wall, it gives off to the viscera several median vessels, known successively as the cœliac (of which the hepatic is a branch), anterior mesenteric (of which the genital is a branch), lienogastric, and posterior mesenteric, and to the kidneys several paired renal arteries.

Veins.

The sinus venosus receives the whole of the blood returning to the heart, by a number of very large veins which are called *sinuses*, though, unlike the sinuses of the crayfish, they do not take the place of capillaries as well as veins in the circulation, but are merely enlarged parts of the veins. The blood from the liver returns direct to the sinus venosus by two *hepatic sinuses* which enter its hinder side. The rest of the blood is returned by two large precavals or *ductus Cuvieri* which join the sinus venosus, one on each side in the pericardium. Into these the blood from the region of the body in front of the fore-fins is conveyed by a pair of large dorsal *anterior cardinal sinuses* and two smaller *inferior jugular sinuses* below the throat. Each anterior cardinal sinus communicates in front with an *orbital sinus* around the eye, and this in turn with a *nasal sinus* around the olfactory organ. A *hyoidean sinus* in the hyoid arch joins the anterior cardinal

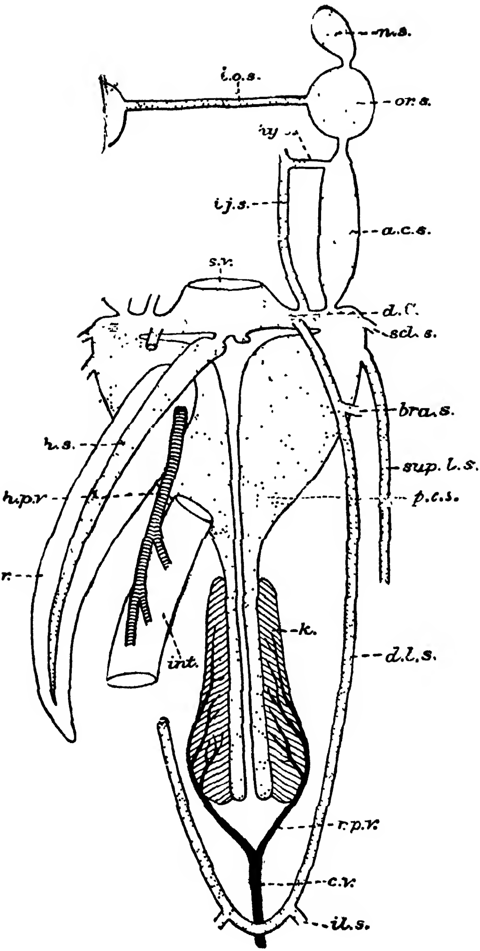


FIG. 164.—A diagram of the venous system of the dogfish.

a.c.s., Anterior cardinal (or internal jugular) sinus; *bra.s.*, brachial sinus; *c.v.*, caudal vein; *d.C.*, ductus Cuvieri, or precaval sinus; *d.l.s.*, deep lateral sinus; *h.p.v.*, hepatic portal vein; *h.s.*, hepatic sinus; *hy.s.*, hyoidean sinus; *i.j.s.*, inferior or external jugular or subbranchial sinus; *i.o.s.*, interorbital sinus; *il.s.*, iliac sinus; *int.*, intestine; *k.*, kidney; *lr.*, liver; *n.s.*, nasal sinus; *or.s.*, orbital sinus; *p.c.s.*, posterior cardinal sinus; *r.p.v.*, renal portal vein; *s.v.*, sinus venosus; *scl.s.*, subclavian sinus; *sup.l.s.*, superficial lateral sinus.

and inferior jugular sinuses. At the outer end of each ductus Cuvieri a *subclavian sinus* enters from the fore-fin. On its hinder side a very large *posterior cardinal sinus* brings back blood from the trunk. The two posterior cardinal sinuses converge backwards, growing narrower, and lie side by side between the kidneys, from which blood passes into them by numerous renal veins. On each flank two *lateral sinuses* return blood from the body-wall, and into one of these open vessels from the fins. Blood from the tail is returned by the *caudal vein*; this divides opposite the hinder ends of the kidneys into two renal portal veins, which run forwards along the outer sides of the kidneys and supply them with blood. Blood from the alimentary canal and spleen is conveyed to the liver by a hepatic portal vein, and thence, after passing through capillaries, is discharged into the hepatic sinuses. It will be noticed that the circulation of the dogfish contains a single circuit only, the blood from the respiratory organs being carried directly to the rest of the body without returning to the heart in the interval. Its general course is summed up in the table on p. 249. The blood cells of the dogfish resemble those of the frog.

Central Nervous System.

The spinal cord of the dogfish resembles that of the frog in most respects and need not be described here. The brain, although in general features it is like that of the frog, shows considerable differences in detail. The foremost region in the middle line is the *cerebrum*, which corresponds to the cerebral hemispheres of the frog, but is single and somewhat globular in shape; its double nature is shown outwardly by a shallow longitudinal groove and internally by the presence of two lateral ventricles. The two olfactory lobes lie at the sides of the cerebrum, each arising from it by a short, stout stalk, which expands into a large mass against the olfactory capsule. The lateral ventricles of the cerebrum are continued into the olfactory lobes. The cerebrum is followed by a thalamencephalon which is somewhat longer than that of the frog. From the hinder part of its thin roof arises the long, hollow, slender pineal stalk, which runs forward over the cerebrum to end in a small swelling below the membrane which covers the anterior

fontanelle. The floor of the thalamencephalon bears a hollow, backwardly directed infundibulum, which differs from that of the frog in being folded, the end passing forwards under the first part, and in bearing at the sides a pair of thick-walled *lobi inferiores* and behind these a three-lobed, thin-walled, vascular expansion known as the *saccus vasculosus*. The pituitary body is said to be

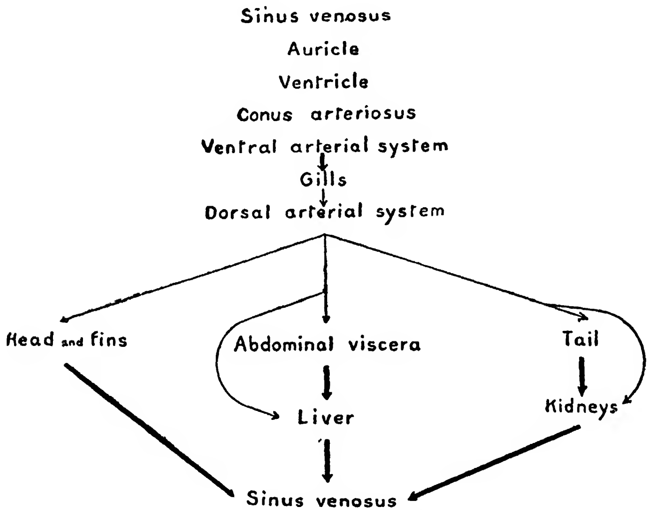


FIG. 165.—A diagram of the circulation of the blood in a dogfish. Thick lines indicate venous blood, narrow lines arterial blood.

a very small tube which lies below the infundibulum attached to the floor of the skull. The mid-brain, which succeeds the thalamencephalon, bears above two optic lobes which stand closer than those of the frog. The cerebellum behind them is much larger than that of the frog and oval in outline, with the long axis fore and aft, and overhangs the optic lobes in front and the thin-roofed fourth ventricle in the medulla oblongata behind it. The medulla is produced forward into a pair of wings, the *restiform bodies*, which lie at the sides of the cerebellum.

Nerves.

The cranial nerves resemble in number and general distribution those of the frog, but the presence of the gills and other differences in the arrange-

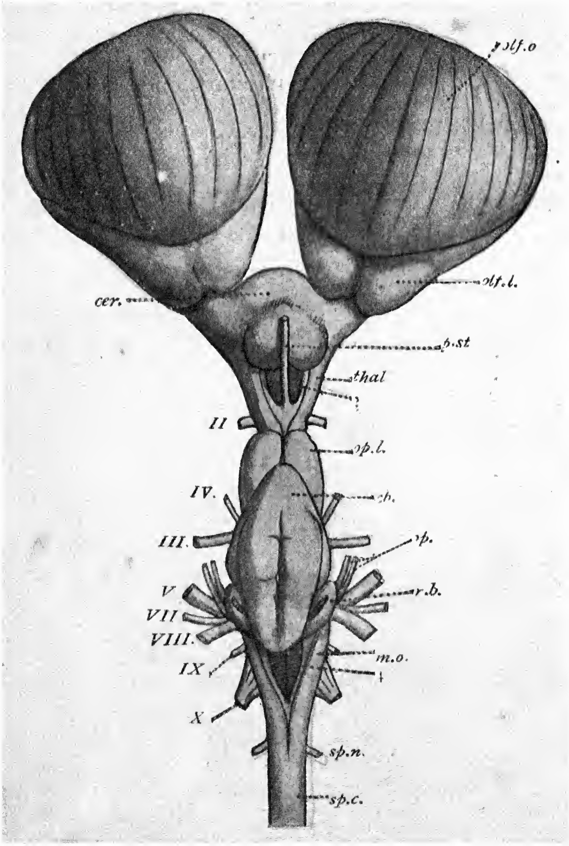


FIG. 166.—The brain of the dogfish, seen from above.

cb., Cerebellum; *cer.*, cerebrum; *m.o.*, medulla oblongata; *olf.l.*, olfactory lobe *olf.o.*, olfactory organ; *op.*, ophthalmic branches of fifth and seventh nerves *op.l.*, optic lobes; *p.st.*, pineal stalk; *r.b.*, restiform body; *sp c*, spinal cord *sp.n.*, spinal nerve; *thal.*, thalamencephalon; 3, 4, third and fourth ventricles *II.-V.*, *VII.-X.*, cranial nerves.

ment of the organs of the head causes the distribution to differ in detail. The olfactory nerves are a bunch of fine threads which pass from the olfactory lobes of the brain into the adjoining olfactory organs. The optic

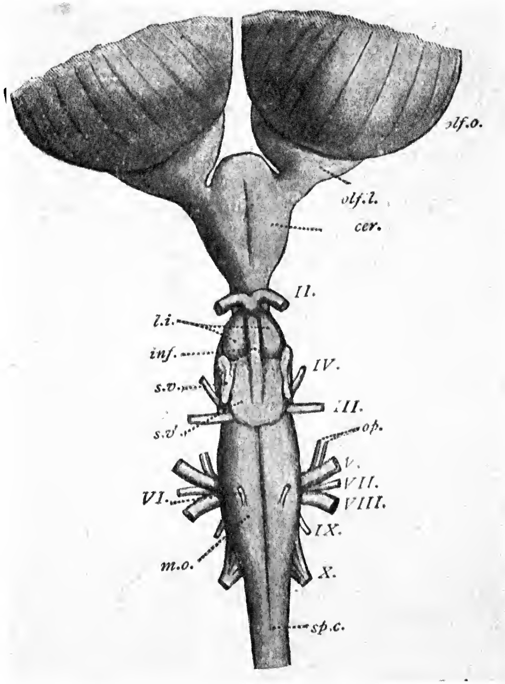


FIG. 167.—The brain of a dogfish, in ventral view.

cer., Cerebrum; *inf.*, return limb of infundibulum, sometimes regarded as the pituitary body; *l.i.*, lobi inferiores; *m.o.*, medulla oblongata; *olf.l.*, olfactory lobe; *olf.o.*, olfactory organ; *op.*, ophthalmic branches of fifth and seventh nerves; *sp.c.*, spinal cord; *s.v.*, lateral lobe of saccus vasculosus; *s.v'.*, median lobe of the same; *II.-X.*, cranial nerves.

nerves pass from the lower surface of the thalamencephalon, each through the optic foramen of the opposite side, to the eyeballs, crossing in a chiasma below the brain. The third or oculomotor nerve of each side, arising from the ventral surface of the mid-brain, passes outwards

through its foramen into the orbit of its own side, where it supplies the superior, inferior, and internal recti muscles of the eye by short branches and gives a long branch across the floor of the orbit to the inferior oblique. The slender fourth, trochlear, or patheticus nerve arises from the dorsal surface of the brain between the optic lobes and the cerebellum, and passes out through a special foramen to supply the superior oblique muscle of its side. The sixth or abducent nerve is also slender. It arises from the ventral side of the medulla and supplies the external rectus muscle, passing through the same foramen as the main branches of the fifth and seventh nerves. The latter two nerves, with the eighth, arise close together from the sides of the medulla below the restiform body. The fifth or trigeminal has three branches. Of these the first, or ophthalmic, parts at once from the rest of the nerve, turns forward within the skull, passes through a foramen in the side of the cranium above the recti muscles, and runs forwards along the outer side of the cranial wall, together with the similar branch of the seventh nerve, to leave the orbit by a foramen above the nasal capsule and be distributed to the skin of the snout. The rest of the nerve leaves the cranium by a large foramen below the recti muscles and runs outwards across the orbital floor as a broad band, which divides into a maxillary branch to the upper jaw and a mandibular branch to the lower. The seventh or facial nerve has a complicated distribution: it possesses (i) an ophthalmic branch which, leaving the cranium by a foramen in front of the similar branch of the fifth, accompanies the latter; (ii) a buccal branch, which joins the main branch of the fifth within the skull, crosses the orbit with it, leaves it before it divides, and is distributed to certain sense organs (neuromast organs, p. 257) of the side of the face; (iii) a small palatine branch which runs across the floor of the orbit behind the fifth nerve and supplies the roof of the mouth; and (iv) a large hyomandibular branch which runs outwards in the hinder wall of the orbit and passes down the hyoid arch. This branch gives off a small prespiracular branch to the anterior wall of the spiracle, after which it passes as the postspiracular nerve behind the spiracle and divides into three branches—an internal and

an external mandibular, and a hyoidean. Of these, it is the internal mandibular which corresponds to the mandibular of the frog. The palatine and hyomandibular branches pass together through the same foramen with the main part of the fifth. The eighth or auditory nerve passes into the auditory capsule to supply the inner ear. The ninth or glossopharyngeal nerve arises from the side of the medulla behind and rather below the eighth, passes

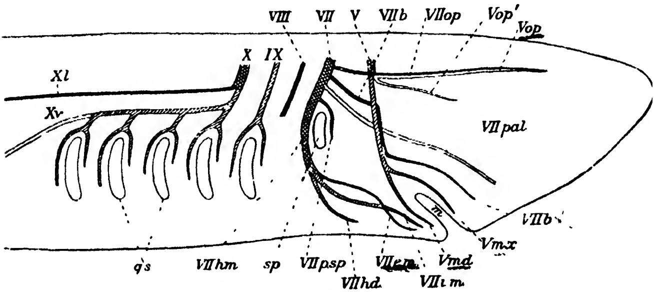


FIG. 168.—A diagram of the distribution of certain cranial nerves in the dogfish. The nerves shown in black are distributed to the system of sense-tubes which includes the neuromast ampullæ (p. 257), lateral line, and labyrinth of the ear. The shaded nerves are distributed to visceral arches.

V.–X., Roots of the nerves; *V.md.*, *V.mx.*, *V.op.*, mandibular, maxillary, and (superficial) ophthalmic branches of the fifth nerve; *V.op'.*, deep ophthalmic nerve, not mentioned in the text, inconspicuous in the rough hound, but large in many other fishes; *VII.b.*, *VII.e.m.*, buccal and external mandibular branches of the seventh nerve, distributed to some of the neuromast ampullæ; *VII.hd.*, *VII.i.m.*, *VII.op.*, *VII.pal.*, *VII.psp.*, hyoidean, internal mandibular, ophthalmic, palatine, and prespiracular branches of the seventh nerve; *VII.hm.*, postspiracular division of hyomandibular branch of seventh nerve; *X.l.*, *X.v.*, lateral line and visceral branches of the tenth nerve; *g.s.*, gill slits; *m.*, mouth; *sp.*, spiracle.

through a passage in the cartilage of the auditory capsule, emerges by its foramen behind the capsule, and turns down the first branchial arch, after giving off a small prebranchial branch to the hyoid arch. The tenth or vagus nerve arises by a number of roots immediately behind the ninth. It leaves the skull by a foramen beside the occipital condyle, and runs backwards along the anterior cardinal sinus, lying just median to that vessel, immediately

against its lining, through which it can be seen if the vein be opened. It represents several nerves fused, and gives off across the floor of the sinus a branch to every branchial arch behind the first, each such branch bearing a prebranchial branch to the preceding arch. Shortly after leaving the skull the vagus gives off a lateral line nerve, which runs along the side of the body, rather deep among the muscles, and supplies an organ in the skin known as the lateral line, which will be mentioned later. After giving off the last of its branches to the branchial arches, the vagus passes downwards to supply the heart and other viscera (Pl. IV.).

These nerves and their principal branches may be summarised as follows:

NAME.	FUNCTION.	DISTRIBUTION.
I. Olfactory	Afferent	Nasal organ.
II. Optic	Afferent	Retina of eye.
III. Oculomotor	Efferent	1 oblique and 3 recti eye-muscles.
IV. Trochlear	Efferent	Superior oblique muscle.
V. Trigeminal	Mixed	
(*a*) Ophthalmic	Afferent	Snout.
(*b*) Maxillary	Afferent	Upper jaw.
(*c*) Mandibular	Mixed	Mandibular arch (lower jaw).
VI. Abducent	Efferent	External rectus muscle.
VII. Facial	Mixed	
(*a*) Ophthalmic	Afferent	Snout.
(*b*) Buccal	Afferent	Side of head.
(*c*) Palatine	Afferent	Roof of mouth.
(*d*) Hyomandibular	Mixed	Hyoid (and mandibular) arches.
VIII. Auditory	Afferent	Ear.
IX. Glossopharyngeal	Mixed	1st branchial (and hyoid) arches.
X. Vagus	Mixed	
(*a*) Lateral line	Afferent	Lateral line sense organ.
(*b*) Branchial branches	Mixed	Branchial arches 2–5.
(*c*) Visceral	Mixed	Viscera.

The comparison of the cranial nerves with dorsal and ventral roots of spinal nerves which was made with regard to the frog (p. 76) holds good for the dogfish and all other vertebrates. A feature of their distribution which was not obvious in the latter animal is that certain of them (the fifth, seventh, ninth, and tenth) give branches to the visceral arches. Each such branch gives off an afferent *pretrematic* branch to the arch in front of that which it chiefly serves (in the case of the fifth nerve this branch passes to the upper jaw). The *post-trematic* branch is

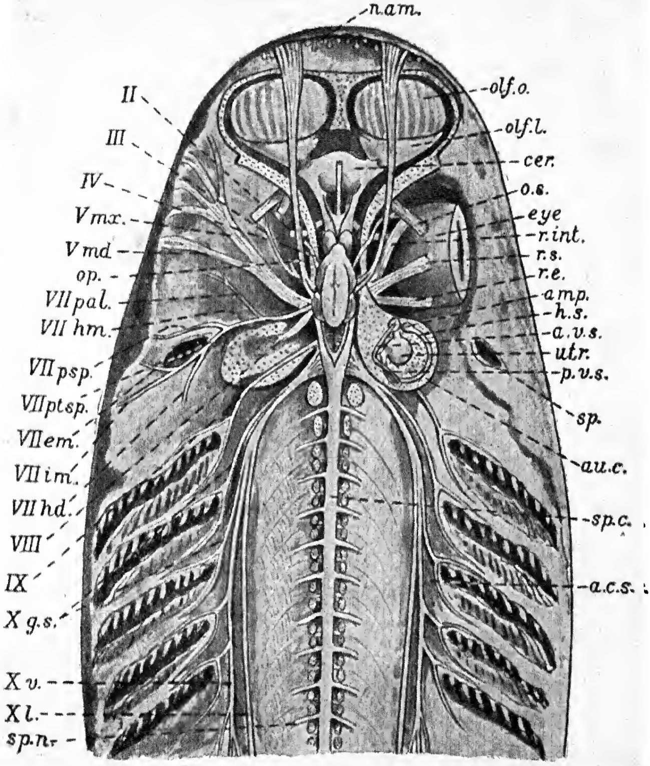


PLATE IV.—A dissection of the nervous system and sense organs of the dogfish.

On the left: nerves labelled as in Figs. 166–170.
On the right: *a.c.s.*, anterior cardinal sinus; *a.v.s.*, *amp.*, *h.s.*, *p.v.s.*, *utr.*, parts of labyrinth, labelled as in Fig. 45; *au.c.*, auditory capsule; *cer.*, *olf o.*, *olf.l.*, *sp.c.*, as in Fig. 166; *n.am.*, neuromast ampullæ; *o.s.*, *r.e.*, *r.int.*, *r.s.*, *sp.*, as in Fig. 169.

efferent or mixed. The spinal nerves of the dogfish are more numerous than those of the frog, but in their general structure and arrangement resemble them. The dorsal and ventral roots by which each arises from the spinal cord pass through the wall of the neural canal by small notches in the hinder edges of the intercalary pieces and neural arches respectively. The sympathetic system is irregular

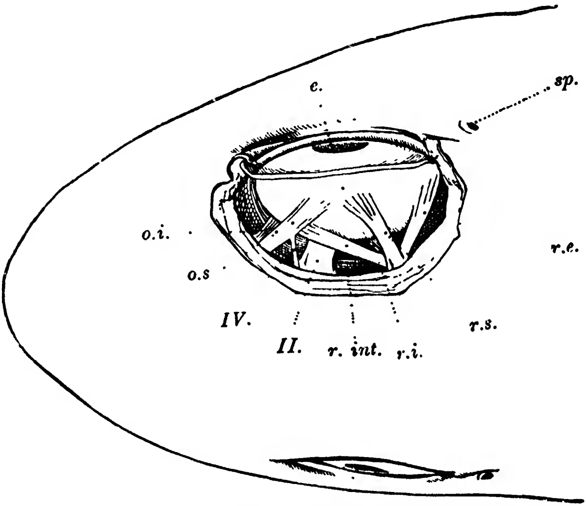


FIG. 169.—The head of a dogfish, seen from above with the right orbit opened.

e., Eyeball; *o.i.*, *o.s.*, inferior and superior oblique muscles; *r.e.*, *r.i.*, *r.int.*, *r.s.*, external, inferior, internal, and superior recti muscles; *sp.*, spiracle; *II.*, optic nerve; *IV.*, fourth nerve.

and difficult of dissection in the dogfish, but in the main outlines of its plan it resembles that of the frog.

Sense Organs. Each of the olfactory organs of the dogfish (Figs. 162 and 166) is a sac enclosed in the olfactory capsule of its side of the body. It opens externally by the nostril, but has no internal opening into the mouth. Its walls are thrown into vertical folds covered with an epithelium which contains sense cells. The eyes resemble in all important respects those of the frog, and need not here

be described. On account, however, of their larger size, they are more suitable objects for the study of the eye muscles. Like the eyes of the frog and those of all other vertebrate animals, each of them is moved by six muscles, which arise from the inner wall of the orbit. Four of these, known as recti, arise together near the hinder end of the orbit and diverge to be inserted into the eyeball at various points. The *rectus superior* runs outwards and forwards and is in-

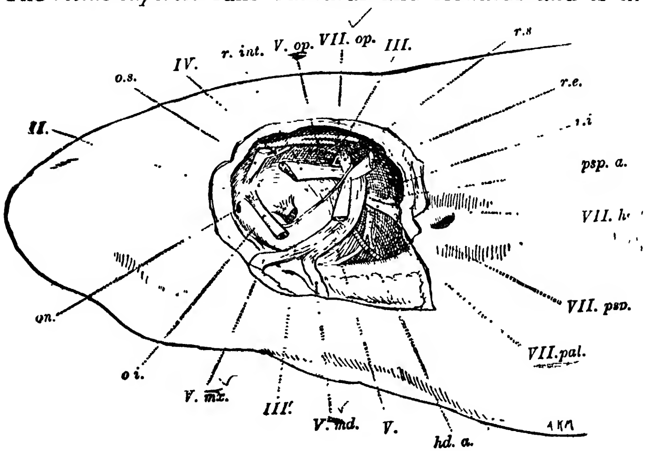


FIG. 170.—The left side of the head of a dogfish with the orbit opened and the eye removed.

ha.a., Hyoidean artery; *on.*, orbitonasal foramen; *psp.a.*, postspiracular artery; *o.i.*, *o.s.*, *r.e.*, *r.i.*, *r.int.*, *r.s.*, eye muscles as in Fig. 265; *II.-VII.*, cranial nerves; *III.*, third nerve entering the orbit and dividing to supply eye muscles; *III'.*, its branch to the inferior oblique muscle; *V.md.*, *V.mx.*, *V.op.*, mandibular, maxillary, and ophthalmic branches of fifth nerve; *VII.hm.*, *VII.op.*, *VII.pal.*, *VII.psp.*, hyomandibular, ophthalmic, palatine, and prespiracular branches of seventh nerve.

serted into the upper side of the eyeball. The *rectus inferior* runs a similar course below the eyeball to be inserted into its lower surface. The *rectus internus or medialis* runs forwards between the eyeball and the cranial wall and is inserted into the front side of the former. The *rectus externus or lateralis* runs outwards behind the eyeball, into whose hinder surface it is inserted. The remaining two muscles are known as obliqui. They arise together near the anterior

end of the orbit and pass outwards and backwards to their insertions into the eyeball. The *obliquus superior* is inserted into the dorsal surface of the eyeball just in front of the superior rectus; the *obliquus inferior* is inserted in a corresponding position in front of the insertion of the inferior rectus upon the lower side of the eyeball. By the contraction of various combinations of these muscles the eyeball may be turned in any direction. The lower eyelid is movable. The structure of the internal ear (Pl. IV.) is essentially similar to that of the frog. Its communication with the external water and the absence of a drum have already been mentioned (p. 229). Besides these sense organs, which are found in all vertebrates, fishes possess a peculiar system, known as the *neuromast organs*, which are not found in any other adult vertebrates with the exception of certain newts. These consist of sensory patches of the epidermis containing sense cells, which bear short, stiff sense hairs, and supporting cells. In the dogfish the sense patches are placed at the bottom of tubes in the skin, which are filled with slime or mucus. The most conspicuous of these tubes runs along the side of the body, its position being marked by a rather indistinct *lateral line* (Figs. 148, 150). It opens upon the surface of the body at intervals. On reaching the head the lateral line divides into two branches, which pass above and below the eye, branch again, and rejoin in front upon the snout. Besides this branching system of tubes there are, upon the snout, others which pass straight inwards through the skin and end in swellings or ampullæ (Fig. 155, *n.am.*) which contain sense patches. These can be found by pressing the skin and thus squeezing the mucus out of them in little drops. The neuromast organs are supplied by a special set of nerve fibres, which join the same portion of the grey matter of the brain with which the fibres of the auditory nerve are connected, but enter the brain by various nerves (Fig. 168), of which the principal are the ophthalmic branch of the seventh and the lateral line branch of the tenth nerve. The function of these organs is the detection of vibrations in the water of too low a frequency to be detected by the ear. The latter must be regarded as a specially highly developed part of the same system as the neuromast organs.

CHAPTER XIV

THE RABBIT

Habits.

THE Rabbit, *Lepus cuniculus,* is one of the animals that have been introduced into Britain by man. Its original home was in the countries at the western end of the Mediterranean. Thence it has spread or been carried by man throughout most of Europe and into various other parts of the world, where its adaptability and great fertility have enabled it to thrive to such an extent that often, as notably in Australia, it has become a serious nuisance. Its habits are well known. It is herbivorous, and will eat a great variety of plants. It is gregarious, and digs for itself burrows into which it retires to sleep or at the approach of danger and to rear its young. On this account it prefers districts where the soil is light and easily worked, though it will live even in wet places if these bear dense vegetation, in which it can form runs instead of burrows. As befits its defencelessness, it is very wary, and its habit of living in societies gives each individual a better chance of receiving warning of the approach of an enemy. Its custom of feeding chiefly at dusk has similar advantages in enabling it to escape observation. It lives seven or eight years and breeds four times, or oftener, in a year, beginning to breed at six months old. As each litter contains from five to eight young, its natural rate of reproduction is enormous and enables it to pay the heavy toll taken by its numerous enemies. It is readily domesticated, and various fancy races have been produced by breeders.

External Features.

The rabbit is covered with *fur*, which in the wild race is of an inconspicuous, tawny-grey colour save on the under side of the short, upright tail, where it is white. When, on an alarm, the animal scampers off to its burrow, the white patch on its

tail is conspicuous, and this, though no doubt it enables an enemy to follow the fugitive, has probably advantages to the species in guiding and warning other members of the society. The head is separated from the trunk by a distinct *neck*, a feature which we have not met with in the dogfish or frog. The long *external ears or pinnæ* are another new feature. The eyes have *movable upper and lower lids* with a few *eyelashes*, and a small third eyelid lies as a white membrane in the inner corner and is used in cleaning the cornea. This eyelid is rudimentary in man. The nostrils are two oblique slits at the end of the snout, and lead internally into the pharynx. We have seen that in the dogfish the nostrils do not open internally and in the frog they open into the front of the mouth. The upper lip is a "hare lip," cleft in the middle, the cleft being continuous with the nostrils and exposing the great front teeth. On the sides of the snout and round the eyes there are strong tactile hairs or *vibrissæ* which correspond to the so-called "whiskers" of the cat. There is *no cloaca*, the anus and urinogenital openings being separate, and the latter in front of the former, in the male on the end of a *penis*, in the female within a slit-like *vulva* which contains in front a small *clitoris* corresponding to the penis. Beside the penis in the male lie the *scrotal sacs*, into which the testes of the adult descend, but there is no hanging scrotum. Along the breast and belly of the female there are four or five pairs of *teats* on which open the milk glands of the *mammæ*, which we meet here for the first time. At the sides of the anus are a pair of hairless depressions, into which open the ducts of the *perineal glands*, to whose secretion is due the peculiar smell of the rabbit. The limbs have the same general shape as those of the frog and other land vertebrates, being of the type known as *pentadactyle* (p. 40), though in the rabbit, while the fore-limbs have five digits, the hind-limbs have only four. The digits end in horny *claws*. The fore-limbs are shorter than the hind-limbs, and in running the animal does not tread upon the whole sole of the foot, carrying the heel above the ground.

The closely related Common Hare differs from the rabbit in its greater size, the greater length of the hind-limb, the black tips of the very long ears, the absence of

Hares.

the burrowing habit, and the fact that the young, which are born in the open, are hairy, whereas those of the rabbit, born in the shelter of a burrow, are naked. The hare is a native of Britain and other parts of Northern Europe. The Mountain Hare is more like the rabbit in the shape of its body, but has black tips to the ears and turns grey or white in cold weather.

The rabbit is a backboned animal, with all that we have seen that to imply. Like that of all Vertebrata, its skin is

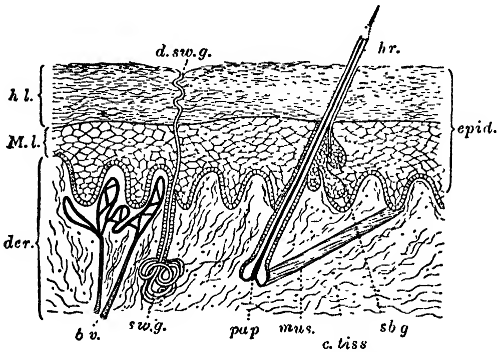


FIG. 171.—A diagram of a section through the skin of a mammal. Highly magnified.—From Shipley and MacBride.

b.v., Blood vessels; *c.tiss.*, connective tissue of dermis; *d.sw g.*, duct of sweat gland; *der*, dermis or corium; *epid.*, epidermis; *h.l.*, stratum corneum or horny layer of the same; *hr.*, hair; *mus.*, muscles by which the hair may be made to stand on end; *M.l.*, Malpighian layer; *pap.*, hair papilla; *sb.g.*, sebaceous gland; *sw.g.*, sweat gland.

General Anatomy and Skin.

covered with a stratified epidermis. There are no scales, but cellular outgrowths of the epidermis form *hairs*, which are peculiar to the warm-blooded, suckling animals known as *Mammalia*. Each hair is embedded in a pit or follicle of the epidermis, at the bottom of which it arises by the growth of the epidermic cells which cover a vascular papilla. The bristles of the crayfish or of hairy caterpillars, and the setæ of the earthworm, are not true hairs, but cuticular structures *secreted* by the epidermis. The skin also contains *sweat or sudorific glands* and *grease or sebaceous glands* which

secrete an oily substance into the hair follicles. The glands and follicles are parts of the epidermis, but project inwards into the dermis. Below the latter is a layer of fatty tissue. The muscles of the adult rabbit, as in the frog, show little trace of the segmentation which they have in the early stages of development. The general arrangement of the internal organs resembles that of the frog, but a muscular partition, the *midriff or diaphragm*, separates off from the

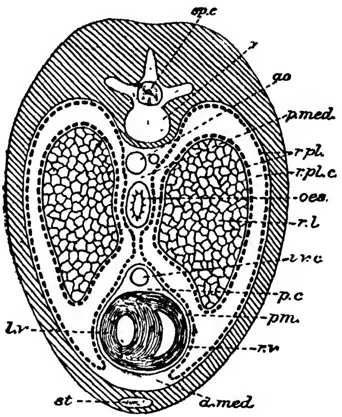


FIG. 172 —A diagram of a transverse section through the thorax of a rabbit.

a.med., Ventral part of mediastinum; *ao.*, aorta; *i.v.c.*, inferior vena cava; *l.v.*, left ventricle; *œs.*, œsophagus; *p.c.*, pericardial cavity; *p.med.*, dorsal part of mediastinum; *pm.*, pericardium; *r.l.*, right lung; *r.pl.*, right pleura; *r.pl.c.*, right pleural cavity; *r.v.*, right ventricle; *sp.c.*, spinal cord; *st.*, sternum; *v.*, vertebra.

peritoneal cavity of the abdomen a *chest or thorax* in the breast region, where lies the pericardium, with on each side a *pleural cavity*, into which the lung of its side projects. The lining of each pleural cavity is known as a *pleura*, and of course covers the lung as well as the inside of the thorax. The heart in its pericardium does not lie free in the cavity of the chest, as that of the frog does in the anterior part of its pleuroperitoneal cavity, but is fastened to the dorsal and ventral walls of the thorax by a double sheet of membrane,

each sheet forming the inner wall of a pleural cavity. Between the sheets is a lymph-space known as the *mediastinum*. In the dorsal part of this space lie the aorta, certain other blood vessels, and the œsophagus; its middle part is quite filled by the pericardium, with which it fuses; and in its ventral part lies the thymus.

Skeleton: Backbone. The skeleton of the rabbit in its main features, and to a considerable extent in its details, resembles that of the frog, but only in its broadest outlines can a correspondence with that of the dogfish be traced. It is almost entirely bony, though most of it is first laid down in cartilage, which persists upon the surfaces of the joints and elsewhere. The vertebræ[1] are much like those of the frog (p. 27), each of them being entirely bony and consisting of a body or centrum with two neural arches, which enclose above the centrum a vertebral foramen, surmounted by a neural spine or spinous process. As in the frog, each arch bears in front an upward-facing facet or superior articular process or prezygapophysis and behind a downward-facing inferior articular process or post-zygapophysis which fits on to the corresponding prezygapophysis of the next vertebra, while at the side a transverse process projects, and at each end there is an intervertebral notch for the passage of a spinal nerve, the adjacent notches of two vertebræ enclosing an *intervertebral foramen*. Each end of each centrum, with the exception of the first, is flat, and has applied to it in the young rabbit a thin bony disc or *epiphysis*, which fuses with it when growth is complete. There is more difference between the vertebræ than in the frog, the backbone being divided into five sections, the neck or cervical, chest or thoracic, loin or lumbar, hip or sacral, and tail or caudal regions. In the *cervical region* there are seven vertebræ, which may be recognised by the fact that each of the transverse processes is pierced by an opening, known as its *foramen*, through which the vertebral artery passes, so that there is formed an interrupted *vertebrarterial canal* on each side. This is due to the fusion with the vertebræ of short cervical ribs in such a way as to constitute a compound transverse

[1] The general characters of the vertebræ of the rabbit may be well studied in that known as the second lumbar (see below).

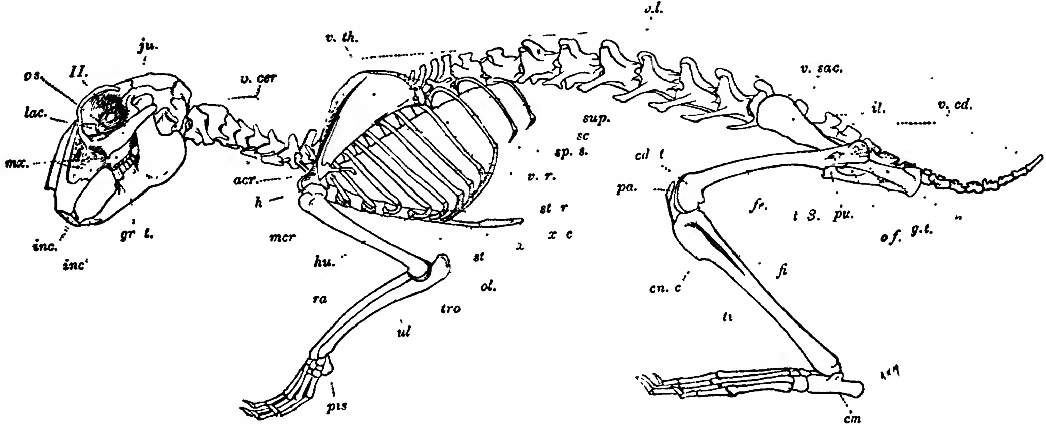


FIG. 173.—The skeleton of a rabbit.

acr., Acromion; *cd t.*, condyles for tibia; *cm.*, calcaneus; *cn.c.*, cnemial crest; *fe.*, shaft of femur; *fi.*, fibula; *g.t.*, great trochanter; *gr.t.*, premolar and molar teeth; *h.*, head of humerus, fitting into glenoid cavity; *hu.*, shaft of humerus; *il.*, ilium; *inc.*, upper incisor teeth of the left side; *inc'.*, lower incisor tooth; *is.*, ischium; *ju.*, jugal bone; *lac.*, lacrymal bone; *mcr.*, metacromion; *mx.*, maxilla; *o.f.*, obturator foramen; *ol.*, olecranon process; *os.*, orbitosphenoid bone; *pa.*, knee-cap; *pis.*, pisiform bone; *pu.*, pubis; *ra.*, radius; *sc.*, scapula; *sp.s.*, spine of scapula; *st.*, sternum; *st.r.*, sternal ribs; *sup.*, suprascapula; *t.3*, third trochanter; *ti.*, tibia; *tro.*, trochlea; *ul.*, ulna; *v.cd.*, *v.cer.*, *v.l.*, *v.sac.*, *v.th.*, caudal, cervical, lumbar, sacral, and thoracic regions of the backbone; *v.r.*, vertebral ribs; *x.*, xiphisternum; *x.c.*, xiphoid cartilage; *II.*, foramen for optic nerve. The clavicle and hyoid are not shown. Enlarged figures of the parts of the skeleton are given in the succeeding figures and in Plate V.

process which encloses a space. The first vertebra, known as the *atlas*, is ring-shaped, with a very large vertebral foramen and no centrum. The ring is divided by a ligament into an upper part, through which the spinal cord passes, and a

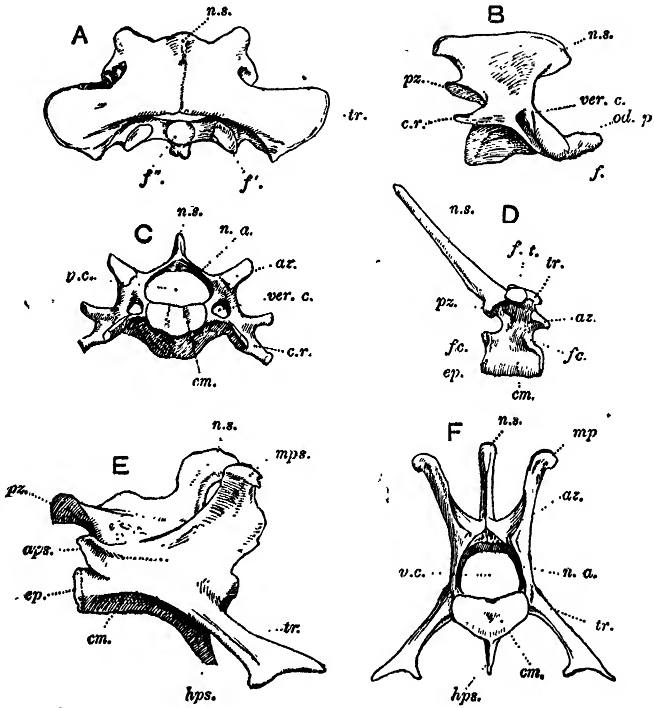


FIG. 174.—Vertebræ of a rabbit.

A, Atlas, from above; *B*, axis, from the right; *C*, one of the middle cervical vertebræ, from in front; *D*, fourth thoracic vertebra, from the right; *E*, second lumbar vertebra, from the right; *F*, the same from in front.

aps., Anapophysis; *az.*, prezygapophysis; *cm.*, centrum; *c.r.*, cervical rib; *ep.*, epiphysis; *f.*, facet on axis for articulation with atlas: *f′.*, corresponding facet on atlas; *f″.*, facet on atlas for odontoid process; *f.c.*, *f.c′.*, demi-facets for heads of ribs; *f.t.*, facets for tuberculum; *hps.*, hypapophysis; *mps.*, metapophysis; *n.a.*, neural arch; *n.s.*, neural spine; *od.p.*, odontoid process; *pz.*, postzygapophysis; *tr.*, transverse process; *v.c.*, vertebral foramen; *ver.c.*, foramen of transverse process.

See also Plate V., Figs. A and B.

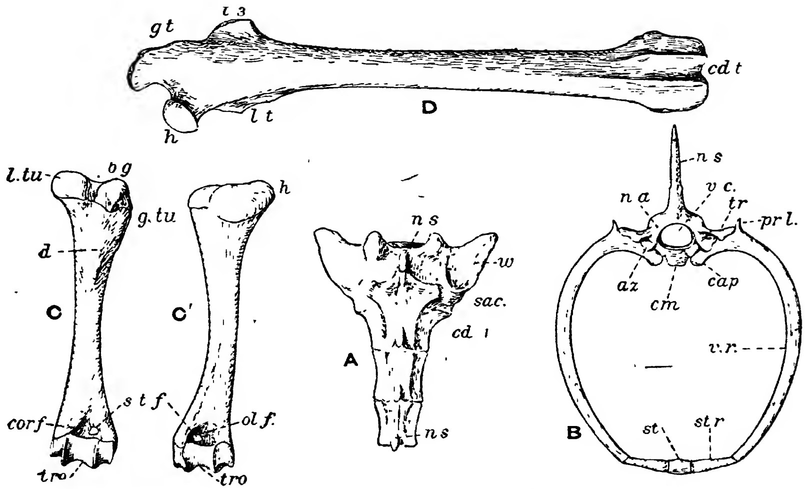


PLATE V.—Bones of the rabbit.

A, The sacrum, from above; *B*, a segment of the skeleton of the thorax, from in front; *C*, the left humerus, from in front; *C′*, the same, from behind; *D*, the left femur, from in front.

az., Prezygapophysis; *b.g.*, bicipital groove; *cap.*, capitulum; *cd.t.*, condyles for the tibia: *c.d.*1, first caudal vertebra; *cm.*, centrum; *cor.f.*, coronoid foramen; *d.*, deltoid ridge; *g.t.*, great trochanter; *g.tu.*, greater tuberosity; *h.*, head; *l.t.*, lesser trochanter; *l.tu.*, lesser tuberosity; *n.a.*, lamina of neural arch; *n.s.*, neural spine; *ol.f.*, olecranon fossa; *pr.l.*, process for the attachment of ligament: *s.t.f.*, supratrochlear foramen; *sac.*, sacral vertebra; *st.*, sternum; *st.r.*, sternal rib; *t.*3, third trochanter; *tr.*, transverse process; *tro.*, trochlea; *v.c.* vertebral foramen; *v.r.*, vertebral rib; *w.*, process for the ilium.

lower part, into which fits a peg, the *dens or odontoid process*, projecting forward from the centrum of the second vertebra. This peg represents the centrum of the atlas removed from it and fused with the vertebra behind. The transverse processes of the atlas are very broad, and the front side of the vertebra has two very large articular surfaces for the occipital condyles. The second vertebra is known as the *axis or epistropheus*. It has a long, crest-like neural spine and bears the odontoid process. The remaining cervical vertebræ are short and broad, with low neural spines, except that of the seventh. The *thoracic region* contains twelve or thirteen vertebræ, which are characterised by bearing movably articulated ribs. The neural spines are long, the transverse processes short and stout, and each, in the first nine vertebræ, provided on the under side with a facet or "costal pit" for articulation with the tubercle of a rib, presently to be described. The front end of the centrum (in the first nine the hinder end also) bears on each side a facet for the head of the rib. The hinder vertebræ of this set gradually become more like those of the *lumbar region*. These are usually seven in number. They are characterised by their large size and the great development of their processes, the prezygapophysis being borne upon the inner side of a large *metapophysis* and the hinder intervertebral notch being overhung by a small *anapophysis*. In the first two the centrum bears a median ventral *hypapophysis*. The lumbar vertebræ have no ribs. There is usually only one *sacral vertebra*, but sometimes two are found. These vertebræ are large and bear at the sides a pair of wing-like expansions, which support the hip girdle and are probably ribs fused with the vertebra. A certain number of the succeeding vertebræ are fused with the true sacral vertebra, the whole mass being known as the *sacrum*. The *caudal region* contains about eighteen vertebræ, ~~of~~ which the first three or four are fused with the sacral They grow smaller from before backwards, losing their processes and becoming degenerate:

Ribs and Breastbone. The *ribs* are present as independent elements only in the thoracic region. They are curved, bony rods, articulated with the vertebræ. Those of the first nine pairs are connected at their lower ends with the breastbone by bars of calcified cartilage known

as their *sternal portions* or as *sternal ribs.* The end which articulates with the vertebra has a knob known as the *head or capitulum.* The first nine pairs have a second facet on the dorsal side at a short distance beyond the head. This is

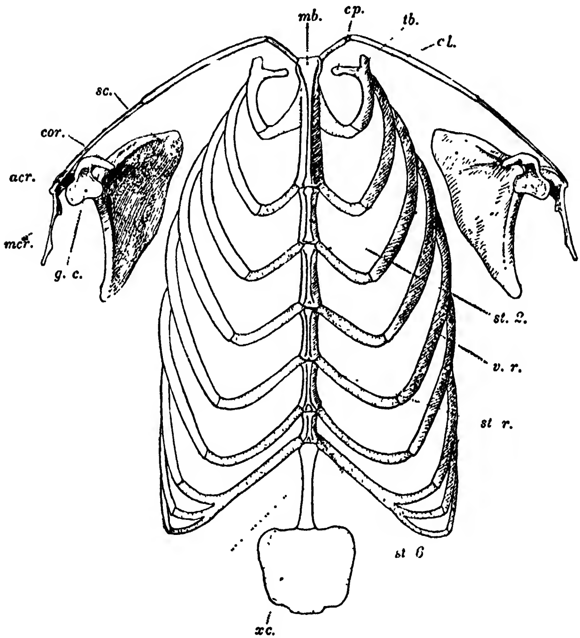


FIG. 175.—The breastbone and shoulder girdle of a rabbit, seen from below and somewhat from in front.

acr., Acromion; *cl.*, clavicle; *cor.*, coracoid process; *cp.*, capitulum; *g.c.*, glenoid cavity; *mb.*, manubrium; *mcr.*, metacromion; *sc.*, scapula; *st.r.*, sternal portion of a rib; *st.*2, *st.*6, second and sixth sternebræ; *tb.*, tuberculum; *v.r.*, vertebral portion of a rib; *x.*, xiphisternum; *x.c.*, xiphoid cartilage.
See also Plate V., Fig. B.

for articulation with the transverse process of the vertebra, and immediately beyond it, for the attachment of ligaments, is a short projection, together with which it forms the *tuberculum.* The sternal portions of the first seven pairs articulate directly with the sternum; those of the eighth and

ninth are connected with the ribs in front of them. The last three pairs have no sternal portions and no tubercula. The breastbone or sternum is a long, narrow rod, divided into segments, and lying in the mid-ventral line of the thorax. The first segment is the *manubrium*. It is the largest and is flattened from side to side. Behind it come four segments of equal size, then a very short segment, and finally the *xiphoid process or xiphisternum*, a long, slender rod, which bears behind a horizontal plate of cartilage. The ribs of the first pair articulate with the sides of the manubrium, and the succeeding six pairs between the segments.

Skull.

The skull[1] contains the same regions that we have met with in the frog and dogfish, but it consists practically entirely of bones, which meet one another by jagged *sutures*.

The cranium or brain-case proper is relatively short, lies almost wholly behind the orbits, and is not in a line with the facial region, which is bent downwards at an angle of 60° upon it. Its bones are arranged in a series of three rings. (1) The *hinder or occipital ring* consists of four cartilage bones (p. 31). The *basioccipital* is a flat bone which forms the floor of the ring, including the lower edge of the foramen magnum and a small part of each occipital condyle. The *exoccipitals* make the sides of the ring, bounding the foramen laterally and forming the greater part of the condyles. The *supraoccipital* is a large, median bone which roofs the occipital ring. (2) In the *middle or parietal ring* there are both cartilage and membrane bones. It abuts on the occipital ring above and below, but at the sides is separated from it by the auditory capsules and squamosal bone. The floor of the cranium in this region is formed by a cartilage bone known as the *basisphenoid*, which lies in front of the basioccipital. It is triangular with the apex truncated and placed forwards, and upon its upper surface is a hollow, known as the *sella turcica*, which lodges the pituitary body. The *alisphenoids* are a pair of irregular cartilage bones which lie at the sides of the basisphenoid and form the lower part of the lateral wall of the cranium. The *parietals* are two large, square membrane bones upon the roof of the cranium, separated at the sides from the alisphenoids by the squamosals. The parietals meet in the middle line. Behind there is wedged in between them and the supraoccipital a small median *interparietal*. (3) The *foremost or frontal ring* contains a narrow median ventral cartilage bone known as the *presphenoid*, which lies in

[1] The skull of the dog is in some respects a more suitable example than that of the rabbit for the preliminary study of a mammalian skull. Good accounts of it may be found in Flower's *Osteology of the Mammalia*, Reynolds' *Vertebrate Skeleton*, and other works.

front of the basisphenoid and is connected with it by cartilage. With the presphenoid are fused at the sides a pair of cartilage bones known as the *orbitosphenoids*, which form the lower part of the lateral walls of the cranium in the orbital region. Above them the *frontals*, a pair of large, oblong membrane bones, complete the side walls and form the roof, each bearing a large *supraorbital ridge*. (4) The front wall of the cranium is formed by a partition of cartilage bone, known as the *cribriform plate*, pierced by a number of holes, through which the olfactory nerves pass to the nasal capsules.

We have seen that the occipital and parietal rings are separated on each side of the cranium by a gap, in which stand the auditory capsule

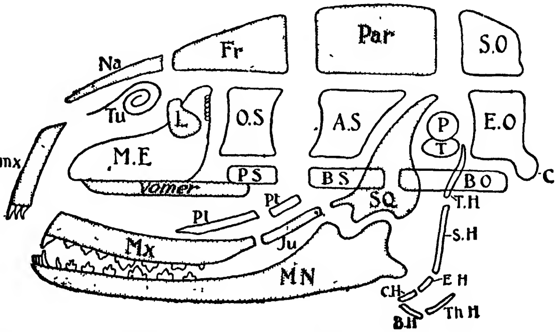


FIG. 176.—A diagram of the skull bones of a mammal (partly after Flower and Weber), the membrane bones shaded.

B.O., Basioccipital; *E.O.*, exoccipital; *C.*, condyle; *S.O.*, supraoccipital; *Par.*, parietal; *Fr.*, frontal; *Na.*, nasal; *Pmx.*, premaxilla; *M.E.*, mesethmoid; *L.*, lachrymal; *Tu.*, turbinal; *P.S.*, presphenoid; *O.S.*, orbitosphenoid; *A.S.*, alisphenoid; *B.S.*, basisphenoid; *SQ.*, squamosal; *P.*, periotic; *T.*, tympanic; *Pl.*, palatine; *Pt.*, pterygoid; *Mx.*, maxilla; *Ju.*, jugal; *T.H.*, tympanohyal; *S.H.*, stylohyal; *E.H.*, epihyal; *C.H.*, ceratohyal; *B.H.*, basihyal; *Th.H.*, thyrohyal; *vomer*; *MN.*, mandible.

and *squamosal*. The latter is a large membrane bone which abuts on the parietal, frontal, alisphenoid, and orbitosphenoid. From its outer surface there arises a stout *zygomatic process*, which bears on its under side the fossa for the articulation of the lower jaw and, beyond the facet, bends downwards to join another bone, the jugal, presently to be mentioned, thus forming the *zygomatic arch or cheek-bone* (see p. 271). From the hinder border of the squamosal a slender *post-tympanic process* extends backwards. The auditory capsule consists of a large cartilage bone known as the *periotic*, which ossifies in development from three centres, one of which represents the prootic. This bone fits loosely into a gap between the squamosal and the exoccipital. Its inner part is dense and known as the *petrous portion*; this encloses the auditory labyrinth. The outer part, which shows on the surface of the skull,

a horizontal partition, which separates an upper olfactory chamber from a lower narial passage (p. 278). The outer sides and floor of the nasal cavities are formed by the palatines, maxillæ, and premaxillæ presently to be mentioned. The surface of the cavities is increased by three pairs of thin and much-folded plates of cartilage bone known as the *turbinals* which project into them from their walls. In the upper jaw there may be recognised the same two series of bones as in the frog, the bones being membrane bones. The *pterygoids* are two vertical plates of bone attached to the lower side of the cranium at the junction of the basisphenoid with the alisphenoid bones. The *palatine bones* are a larger pair, which consist each of a vertical portion, attached above to the ventral side of the presphenoid and behind to the pterygoid, and a horizontal portion which meets its fellow in the median plane in the roof of the mouth (p. 277). There is no quadrate bone. The *premaxillæ* (*ossa incisiva*) are a pair of bones which form the front of the upper jaw and lodge the upper pair of large gnawing teeth. It has a nasal process, which passes backwards beside the nasal bone, and a palatine process, which, like that of the palatine bone, forms part of the floor of the nasal passages. The *maxillæ* are two large irregular bones which lie behind the premaxillæ in the facial region. The main part of each bears the upper grinding teeth. From this arises a palatine process, like those of the premaxillæ and palatine bones, which it connects so as to form a floor to the narial passages, and a zygomatic process, which passes outwards and backwards to form the front part of the zygomatic arch. The zygomatic processes of the maxilla and squamosal are joined by a bar of bone known as the *jugal or malar bone or zygoma*. The *lacrymals* are a pair of small bones which form part of the front walls of the orbits, lying between the frontals and maxillæ.

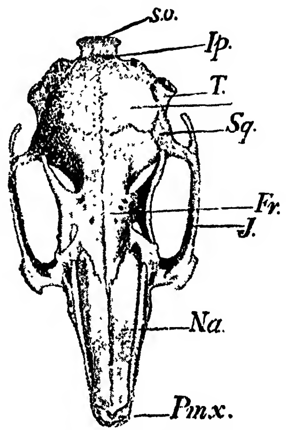


FIG. 179.—A dorsal view of a rabbit's skull.—From Thomson.

S.O., Top of supraoccipital; *Ip.*, interparietal; *T.*, tympanic; *Pa.*, parietal; *Sq.*, squamosal; *Fr.*, frontal; *J.*, jugal; *Na.*, nasal; *Pmx.*, premaxilla.

The lower jaw is composed of membrane bone and represents the dentaries of the frog, Meckel's cartilage, which is present during development, being absent in the adult. The jaw articulates, not with a quadrate but with the squamosal bone (see Figs. 178 and 180). The *hyoid bone*, lying in the floor of the hinder part of the mouth,

represents that part of the visceral skeleton which does not form the jaws and ear ossicles. It consists of a median body, representing the basihyal, and two pairs of backwardly projecting cornua, of which the hinder are the larger. The anterior cornua represent the hyoid arches, and are completed by a series of small separate bones, which connect the hyoid bone with the periotic region of the skull. The posterior cornua represent the first pair of branchial arches.

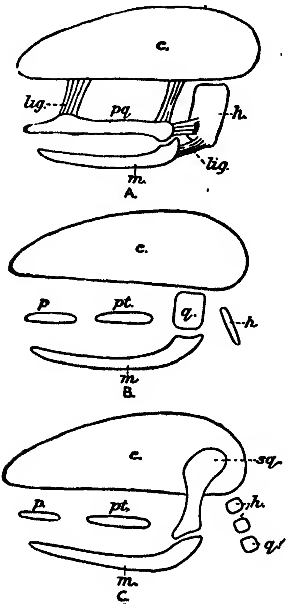


FIG. 180.—A diagram of the jaws of vertebrate animals.

A, The arrangement in the dogfish, in which the hyomandibular takes part in the suspension of the lower jaw (*hyostylic*); *B*, the arrangement in the frog, in which the jaw is suspended by the quadrate (*autostylic*); *C*, the arrangement in the rabbit, in which the lower jaw is suspended by the squamosal.

c., Cranium; *h.*, hyomandibular; *lig.*, ligaments; *m.*, lower jaw; *p.*, palatine; *pq.*, palatoquadrate bar; *pt.*, pterygoid; *q.*, quadrate; *q?*, one of the ear ossicles, possibly representing the quadrate; *sq.*, squamosal.

In most fishes the jaws are hyostylic; in amphibians, reptiles, and birds they are autostylic.

The following openings exist in the wall of each side of the skull: (1) The *anterior nares* at the front end of the nasal capsule, for the nostril. (2) The *anterior* and (3) the *posterior palatine foramina*, a large and a small opening in the palate for the passage of branches of the maxillary nerve and blood vessels between the palate and the nasal cavity. (4) The *lacrymal foramen* between the lacrymal and maxillary bones, for the lacrymal duct which conveys tears into the nose. (5) The *infraorbital foramen* in front of the zygomatic process of the maxilla, for the passage of a branch of the maxillary nerve from the orbit to the face. (6) The *optic foramen*, a large round hole in the orbitosphenoid for the optic nerve. (7) The *foramen lacerum anterius or sphenoidal fissure*, a vertical slit between the basisphenoid and alisphenoids for the third, fourth, sixth, and ophthalmic and maxillary branches of the fifth nerves. In most mammals the last-named branch

passes through a separate opening, the *foramen rotundum*. (8) The *foramen lacerum medium*, an irregular opening on the under side of the skull between the alisphenoid and the periotic. Its anterior part represents the foramen ovale of other mammals and transmits the mandibular branch of the fifth nerve. (9) The *stylomastoid foramen*, a small opening behind the tympanic, through which the seventh nerve leaves the skull. (10) The *foramen lacerum posterius*, an irregular opening on the under side of the skull, between the occipital condyle and the tympanic bulla, through which the ninth, tenth, and eleventh nerves and the internal jugular vein pass. (11) The *carotid foramen*, which pierces the tympanic bone near its inner border, close to the occipital condyle, and transmits the internal carotid artery. (12) The *condylar foramina*, a couple of holes in the exoccipital, just in front of the condyle, through which the hypoglossal nerve passes in two divisions. In connection with the tympanic cavity there are two openings, the *Eustachian canal* at the anterior and inner angle of the tympanic bone, on the under side of the skull, behind the foramen lacerum medium, and the *external auditory aperture* at the end of the neck or spout of the tympanic flask.

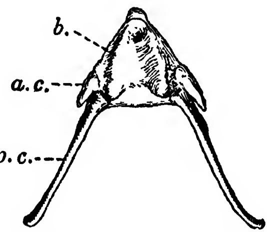


FIG. 181.—The hyoid bone of a rabbit, from above.

a.c., Base of the anterior cornu; *b.*, body; *p.c.*, posterior cornu.

Fore-limb.

The shoulder girdle practically consists of one bone, the scapula, on each side. This is a flat, triangular structure, with the apex downwards and forwards, and bears a prominent external ridge or *spine*, which at its lower end becomes free as an acromion with a long backward *metacromion*. At the apex is the shallow glenoid cavity for the humerus, in front of which a small hook or *coracoid process* represents the coracoid bone of the frog. Along the convex dorsal border lies a narrow cartilaginous suprascapula. The clavicle is a slender, curved bone, lying in a ligament between the acromion and the sternum. In mammals which move the forearm freely, as in man, it is well developed and articulates with acromion and sternum.

The hip girdle is large, and each of its halves is known as an *os innominatum or coxæ*. With the sacrum it forms a ring called the *pelvis*. In each os coxæ may be recognised a large dorsal ilium articulated with the sacrum, a posterior ischium, and a smaller, ventral and anterior pubis which

unites with its fellow in a symphysis. The ischium and pubis are separated by a large *obturator foramen*, above and below which they meet. Above the obturator foramen all three parts of the os innominatum are continuous around the acetabulum, into which the head of the femur fits.

The limbs contain the same bones as in the frog. In the fore-limb the humerus has in front of the head a *bicipital groove* for the tendon of the biceps muscle, bounded by two roughened projections, on the inner side the *lesser tuberosity or small tubercle*, and on the outer side the *greater tuberosity or large tubercle*. At the lower end is a pulley-like trochlea, above which are two *supratrochlear fossæ*, the *coronoid fossa* in front and the *olecranon fossa* behind, a *supratrochlear foramen* putting the two into communication. In the forearm the radius and ulna are distinct but not movable upon one another, the radius lying in front of the ulna. In man the lower end of the radius rotates round the ulna, so that the former lies in front of and obliquely across the latter when the palm faces downwards, but parallel with and outside it when the palm is turned upwards. The position in which the palm is downwards is known as *pronation*, that in which it is upwards as *supination*. In the frog the limb is fixed half-way towards pronation; in the rabbit it is fixed in the prone position. A large olecranon process of the ulna fits into the olecranon fossa. In the wrist all the

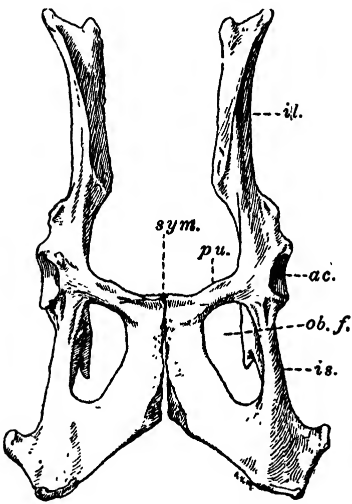


FIG. 182.—The pelvic girdle of a rabbit, from beneath.

ac., Acetabulum; *il.*, ilium; *is.*, ischium; *ob.f.*, obturator foramen; *pu.*, pubis; *sym.*, symphysis pubis.

nine bones of the typical plan are present, arranged, as usual, in a proximal and a distal row with a *central bone or centrale* between them. In the proximal row of three bones the radial is known as the *scaphoid* or *navicular.*

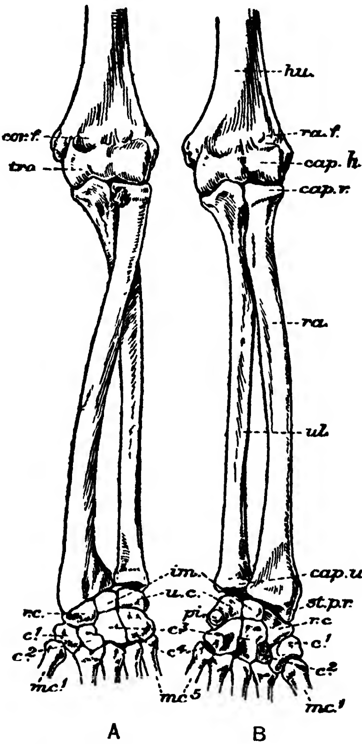


FIG. 183.—Bones of the left fore-limb of man.

A, In pronation; *B*, in supination.

c 1, Os multangulare majus or trapezium; *c.*2, multangulare minus or trapezoid; *c.*3, capitatum or magnum: *c.*4, hamatum or unciform; *cap.h.*, capitulum of the humerus, with which the radius articulates; *cap.r.*, capitulum of the radius; *cap.u.*, capitulum of the ulna; *cor.f.*, coronoid, fossa; *hu.*, humerus; *im.*, os lunare or semilunar; *mc.*1, *mc.*5, first and fifth metacarpals; *pi.*, pisiform; *r.c.*, os naviculare or scaphoid; *ra.*, radius; *ra.f.*, radial fossa; *st.p.r.*, styloid process of the radius; *tro.*, trochlea; *u.c.*, os triquetrum or cuneiform; *ul.*, ulna.

the intermediate as the *semilunar or lunate*, and the ulnar as the *cuneiform or os triquetrum.* In the distal row there are four distal carpals, the first on the inner side being known as the *trapezium or greater multangular*, the second as the *trapezoid or lesser multangular*, the third as the *os*

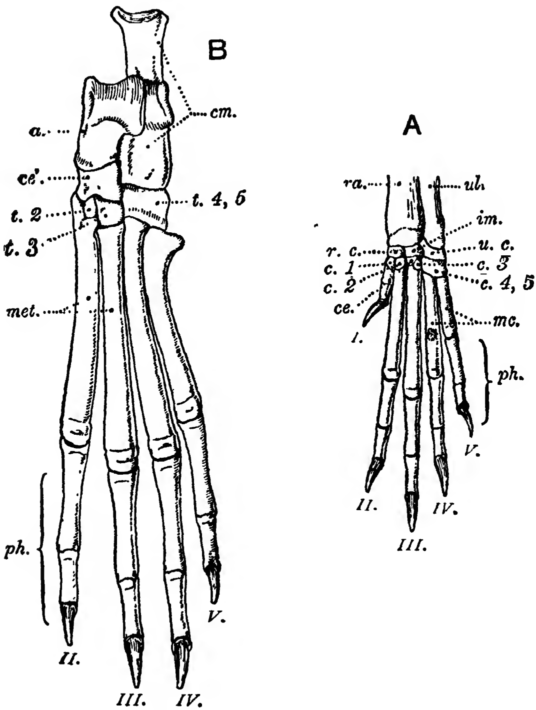


FIG. 184.—The skeleton of the left fore- and hind-feet of a rabbit.

A, Fore-foot; *B*, hind-foot.

a., Astragalus; *c.*1, first distal carpal or trapezium; *c.*2, second distal carpal or trapezoid; *c.*3, third distal carpal or magnum; *c.*4, 5, fused fourth and fifth distal carpals or unciform; *ce.*, centrale; *ce.*, centrale of hind-foot or navicular; *cm.*, fibulare or calcaneus; *im.*, intermedium or semilunar; *mc.*, metacarpals; *met.*, metatarsals; *ph.*, phalanges; *ra.*, lower end of radius with its epiphysis; *r.c.*, radiale or scaphoid; *t.*2, second distal tarsal or mesocuneiform; *t.*3, third distal tarsal or ectocuneiform; *t.*4, 5, fused fourth and fifth distal tarsals or cuboid; *u.c.*, ulnare or cuneiform; *ul.*, lower end of ulnar with its epiphysis; *I.*–*V.*, digits.

magnum or capitatum, and the fourth, which represents two fused, as the *unciform or os hamatum*. On the hinder side of the wrist is a small *pisiform* bone. There are five digits, of which the first is the shortest and the third the longest. In the hind-limb, the femur has a prominent head, below which are three rough prominences, the *greater trochanter* on the outside, the *lesser trochanter* on the inner side, and the *third trochanter* below the great trochanter. At the lower end of the bone are two large condyles for the tibia. A *knee-cap or patella* covers the knee joint and is connected by ligament with the tibia. The tibia and fibula are fused at their lower ends only. The latter is a small splint of bone outside the former, which is straight and stout and bears in front a prominent *cnemial crest*. In the ankle the bones, like those of the wrist, are arranged in two rows with a central bone between them. The first row contains, as in the frog, two bones, the astragalus or talus, which corresponds to a fused tibiale and intermedium, and the fibulare or calcaneus, which lies outside the astragalus and projects backwards to form the heel. The central bone is known as the *navicular*. The distal row consists of three bones, that which corresponds to the missing first digit being absent, and those which correspond to the outer two digits being fused together. The innermost of the remaining bones of the row is known as the *mesocuneiform*, the next as the *ectocuneiform*, and the third as the *cuboid*. The metatarsals are long and there are four digits.

Alimentary System: Mouth, Teeth, and Pharynx.

The mouth differs from that of the frog in the possession of a *palate*—an inner roof which separates from the mouth a *narial passage*. By this passage the approach from the nostrils to the mouth is prolonged backwards, so that the internal nares open into the pharynx instead of into the forepart of the mouth (Fig. 185). The first part of the inner roof is strengthened by the horizontal processes of the premaxillary, maxillary, and palatine bones (p. 271) and is known as the *hard palate*; the hinder part is purely fleshy and is known as the *soft palate*. The narial passage lies above the palate and below the true olfactory chambers. Over the hard palate it is not separated from

these by any roof,and the *nasal septum* between them comes down to divide it into two (p. 270). Over the soft palate it is single, and is separated from the olfactory chambers by a partition, supported by the horizontal flanges of the vomer,

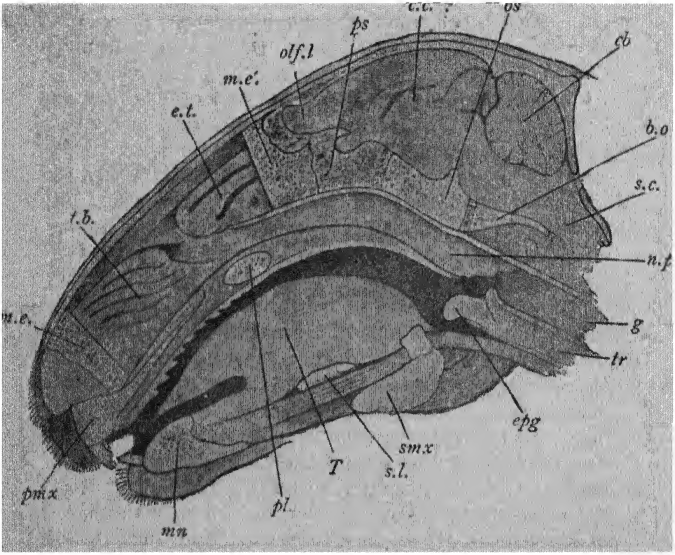


FIG. 185.—A vertical section through a rabbit's head.—From Thomson.

pmx., Premaxilla with incisors; *m.e.*, part of mesethmoid in front region, where narial passage is not separate from olfactory chamber; *m.e'.*, part of same in hinder region, where it divides from one another only the two olfactory chambers, which are here separated by a horizontal partition from the single narial passage (the intermediate part of the mesethmoid is cut away); *t.b.*, maxillary turbinals; *e.t.*, ethmoidal turbinal; *olf.l.*, olfactory lobe of cerebrum; *ps.*, presphenoid; *c.c.*, position of corpus callosum; *bs.*, basisphenoid with depression for pituitary body; *cb.*, cerebellum; *b.o.*, basioccipital; *s.c.*, spinal cord; *n.p.*, narial passage; *g.*, gullet; *tr.*, trachea; *epg.*, epiglottis; *smx.*, submaxillary salivary gland; *s.l.*, sublingual salivary gland; *T.*, tongue; *pl.*, transverse portion of palatine; *mn.*, anterior end of mandible.

representing the true roof of the mouth. Into this hinder part, the *naso-pharynx*, open the Eustachian tubes. The *tonsils* are a pair of pits at the sides of the soft palate near its hind border. The tongue is an elongate, muscular mass attached along most of its length to the floor

of the mouth, but with a free tip in front. It bears papillæ of several kinds which subserve the sense of taste. The teeth differ from those of the dogfish and frog in that (1) they are not all alike, (2) they are inserted in sockets in the jaw, whereas those of the dogfish are embedded in the skin and those of the frog are fused to the jaw, (3) they are borne on the edges of the jaws only, and not on the roof of the mouth like the vomerine teeth of the frog, (4) instead of being continually replaced by the upgrowth of the skin from a groove as in the dogfish, or one by one as in the frog, they are in two definite sets, the *milk teeth* and the *permanent teeth*, of which the first is lost at an early age and replaced for life by the second. The teeth do not form a continuous series as in man, but the front teeth are separated from the grinding teeth by a wide gap or *diastema*, in the position in which the canine or dog teeth should stand, these teeth, with others, being absent from the rabbit. In the upper jaw the *front teeth or incisors* number two pairs, the first pair being long, curved, and chisel-shaped, and the second pair small and hidden behind the first. Unlike the teeth of most mammals, those of the rabbit do not, when they have reached a certain size, narrow at their roots so as to form *fangs* and cease to grow, but continue to be added to below as fast as they are ground down at the top. The six pairs of grinding teeth are all much alike in appearance, having broad, ridged tops, but they are divided into two sets by the fact that the first three, known as *premolars*, are preceded by milk teeth, while the last three, known as *molars*, are not. In the lower jaw there is only one pair of incisors, these being shaped like the first pair above, with which they work in gnawing off the food which is munched fine by the grinders. There are two pairs of premolars and three pairs of molars. It is usual to express the number and arrangement of the teeth of mammals by a *dental formula*. Thus, in the pig, which has a typical set of teeth, the formula is $i\,\frac{3}{3}\,c\,\frac{1}{1}\,pm\,\frac{4}{4}\,m\,\frac{3}{3}$, giving 22 on each side of the mouth, or 44 in all. With this we may compare the dentition of the rabbit, which is $i\,\frac{2}{1}\,c\,\frac{0}{0}\,pm\,\frac{3}{2}\,m\,\frac{3}{3}$,

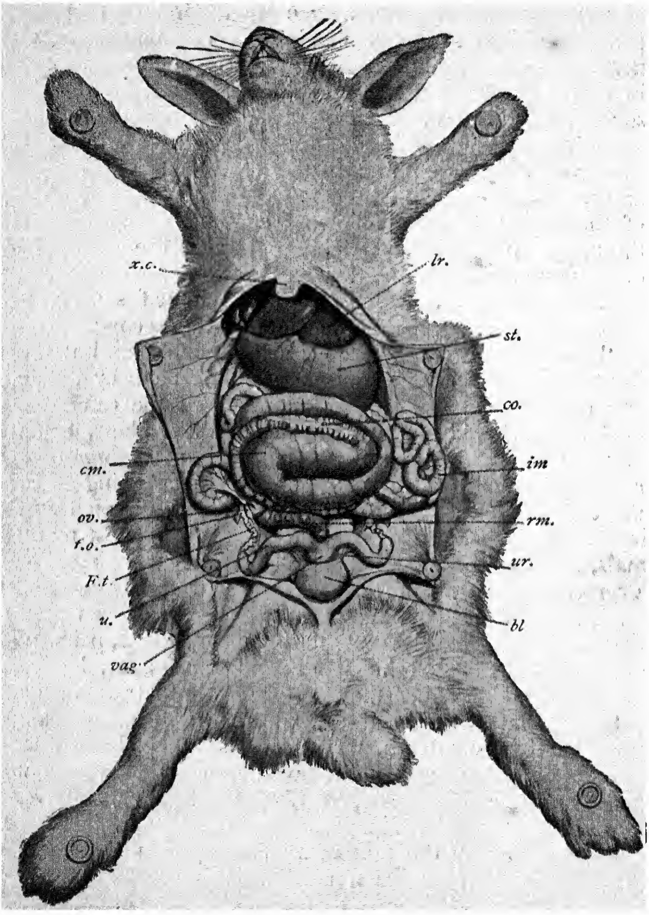


FIG. 186.—The body of a female rabbit with the abdomen opened, the organs being displaced as little as possible.

bl, Bladder; *cm.*, cæcum; *co.*, colon; *F.t.*, Fallopian tube; *f.o.*, fimbriated opening of the oviduct; *im.*, ileum; *lr.*, liver; *ov.*, ovary; *rm.*, rectum; *st.*, stomach; *ur.*, ureter; *ut.*, right uterus; *vag.*, vagina; *x.c.*, xiphoid cartilage. Note also: regions of body (head, neck, chest, abdomen, tail), mouth, nostrils, hare lip, prominent incisor teeth, vibrissæ.

the total for both sides being 28. Four pairs of *salivary glands* pour their secretion into the mouth. The *parotid gland* of each side lies behind the angle of the jaw, the *submaxillary gland* lies against its fellow between the angles of the jaw, the *infraorbital gland* lies below the eye behind the cheek-bone, the *sublingual gland* lies along the inside of the mandible. The saliva moistens the food and contains an enzyme, known as *ptyalin*, which turns starch into sugar. The pharynx receives in front the narial passage and the mouth. Behind, it leads into the gullet above and bears below the glottis, which lies shortly behind the tongue, covered by a flap, known as the *epiglottis*, which is stiffened by a cartilage. Thus in the pharynx there cross one another the passages by which the food passes to the alimentary canal and the air to the lungs. In swallowing, the soft palate is raised and thus closes the posterior nares, while the epiglottis protects the opening of the windpipe, so that when the food is thrust backwards by the muscles of the tongue and pharynx it passes only into the œsophagus. That tube runs backwards through the neck and chest, above the trachea.

FIG. 187.—The duodenum of a rabbit.—From Krause, in part after Claude Bernard.

P., Pyloric end of stomach; *g.b.*, gall bladder with bile duct and hepatic ducts; *p.d.*, pancreatic duct.

Stomach and Intestine.

Shortly after passing through the diaphragm, the œsophagus joins the stomach. This is a wide sac, placed athwart the body cavity and wider at the left or *cardiac end* than at the right or *pyloric end*; it is curved, with the concave side turned forwards, and the œsophagus enters at the bottom of the concavity. The pyloric end communicates with the intestine by a small opening, the *pylorus*, provided with a

sphincter. The small intestine is a narrow, much-coiled tube, seven or eight feet in length. Its first section or duodenum runs from the pylorus along the right side of the abdomen nearly to its hinder end and then turns forward again, forming a loop. In the mesentery between the two limbs of the loop lies the thin, diffuse pancreas,

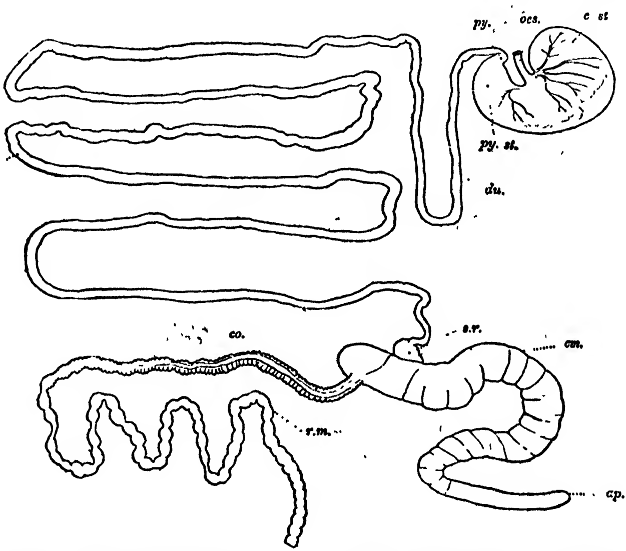


FIG. 188.—The alimentary canal of a rabbit removed from the body and spread out.

ap., Vermiform appendix ; *c.st.*, cardiac end of stomach ; *cm.*, cæcum ; *co.*, colon ; *du.*, duodenum ; *im.*, ileum ; *oes.*, œsophagus ; *py.*, pylorus ; *py.st.*, pyloric end of stomach ; *rm.*, rectum ; *s.r.*, sacculus rotundus.

whose duct enters the returning limb of the loop about three inches beyond the bend. The liver is a large, dark-red, lobed organ slung from the diaphragm by the falciform ligament; in a groove upon its right central lobe lies the elongated, dark-green gall bladder, from which the bile duct runs backwards to open into the dorsal side of the duodenum shortly beyond the pylorus. The remainder of the small intestine is the ileum; it ends in a round swelling known as the *sacculus rotundus*. The lining of the

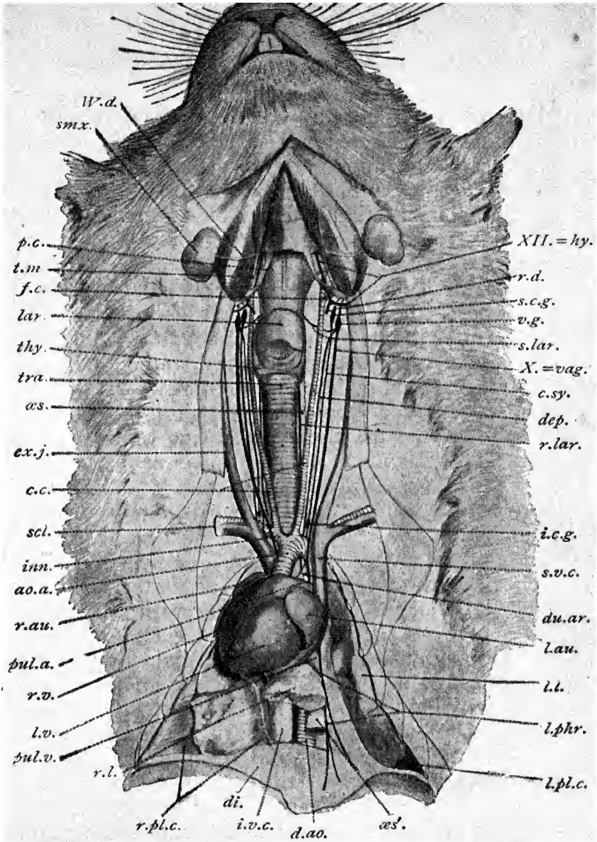


FIG. 189.—A dissection of the neck and thorax of a rabbit. The heart has been displaced a little to the right, and the pericardium removed.

ao.a., Aortic arch; ***c.c.***, common carotid arteries; ***c.sy.***, cervical sympathetic nerve; ***d.ao.***, dorsal aorta; ***dep.***, depressor nerve; ***di.***, diaphragm; ***du.ar.***, ductus arteriosus; ***ex.j.***, external jugular vein; ***f.c.***, point at which the common carotid divides; ***hy.***, hypoglossal nerve; ***i.c.g.***, inferior or posterior cervical sympathetic ganglion; ***inn.***, innominate artery; ***i.v.c.***, inferior vena cava, lying in mediastinum; ***l.au.***, left auricle; ***l.l.***, left lung; ***l.phr.***, left phrenic nerve; ***l.pl.c.***, left pleural cavity; ***l.v.***, left ventricle; ***lar.***, larynx; ***œs.***, œsophagus in neck; ***œs'.***, the same in mediastinum; ***p.c.***, posterior cornu of the hyoid; ***pul.a.***, pulmonary artery; ***pul.v.***, pulmonary vein; ***r.au.***, right auricle; ***r.d.***, ramus descendens; ***r.l.***, right lung, one part bulging into mediastinum; ***r.lar.***, recurrent laryngeal nerve; ***r.pl.c.***, right pleural cavity; ***r.v.***, right ventricle; ***s.c.g.***, superior cervical sympathetic ganglion; ***s.lar.***, superior laryngeal branch of vagus; ***s.v.c.***, superior vena cava; ***scl.***, subclavian artery and vein; ***smx.***, submaxillary gland; ***t.m.***, tendon of mandibular muscle; ***thy.***, thyroid gland; ***tra.***, trachea; ***v.g.***, vagus ganglion; ***vag.***, vagus; ***W.d.***, duct of submaxillary gland (Wharton's duct); ***X.***, ***XII.***, cranial nerves.

small intestine is beset with numerous minute processes or *villi*, by which its surface is increased. At the junction of the small and large intestine is placed a very large tube, the *blind gut or cæcum*, marked by a spiral constriction and ending blindly in a small, finger-like *vermiform appendix*. The sacculus rotundus opens into the cæcum about an inch from the end opposite to the vermiform appendix; the large intestine leaves it at the same end. Two regions may be recognised in the large intestine. The *colon* is a sacculated tube about a foot and a half in length; the rectum is a narrower tube about two and a half feet in length, in which fæcal pellets can be seen.

Ductless Glands.

The spleen is a narrow, crescentic, dark-red body lying close against the convex side of the stomach. The thymus is a soft, pink mass in the mediastinal space at the front of the thorax. The thyroid is a thin, red body consisting of two lobes, one at each side of the larynx, joined by a band across the ventral side of the latter. Suprarenals lie near the aorta.

Respiratory Organs.

The chest or thorax is a closed box whose side walls are formed by the ribs with the muscles between them and its hinder wall by the diaphragm, which divides the main or pleuroperitoneal cœlom, parting two pleural cavities in front from a peritoneal cavity behind (p. 261). The windpipe comprises, besides the larynx, a long tube with rings of cartilage in its wall. This is the *trachea* or windpipe proper, which leads back along the neck and in the thorax divides into two bronchi which join the lungs. In these the bronchi break up into numerous *bronchioles*, which end in minute air sacs. The cavity of the thorax is enlarged from back to breast by an outward movement of the ribs and from head to tail by the movement of the diaphragm, which at rest is convex towards the chest, but when it contracts flattens, thus increasing the size of the thorax. Since the pleural cavities are closed, their enlargement tends to set up a vacuum within them, and thus the lungs, which are not closed, expand to keep them full, drawing in air[1] through the glottis. The air is driven out by the collapse of the chest

[1] That is, the air enters by its own pressure and expands the lungs when the pressure around them in the pleural cavity is lowered.

owing to the elasticity of the lungs as soon as the muscles of inspiration relax, but this movement can be aided by the contraction of certain other muscles, notably those of the belly, which press the viscera against the diaphragm from behind.

The kidneys of the rabbit are a pair of dark-red bodies, convex on the outer side and concave on the inner, which lie on the dorsal wall of the peritoneal cavity, that on the left

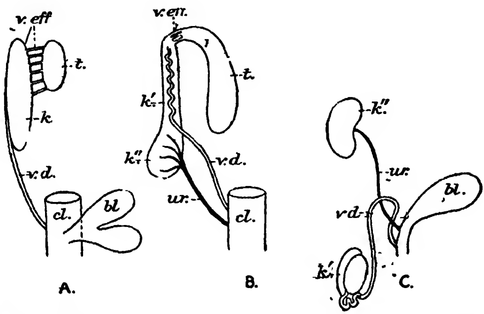


FIG. 190.—Diagrams of the male genital and urinary apparatus of: *A*, The frog; *B*, the dogfish; *C*, the rabbit.

The animal is lying on its back, the organs of the right side are shown, and the bladder is turned to the left.

bl., Bladder; *cl.*, cloaca; *k.*, kidney; *k'.*, anterior region of the same, which discharges through the Wolffian duct (*v.d.*); *k''.*, posterior region, which discharges through a duct of its own, the ureter (*ur.*): in the frog this region is not developed, though it is present in the newt. In the dogfish, as in the newt, the two regions remain continuous and are known as the "mesonephros" and "metanephros." In the rabbit, regions roughly corresponding to those of the dogfish become in the adult the "epididymis" and "kidney" respectively. The "pronephros" or foremost region of the kidney of the embryo has in each case disappeared in the adult. Its history in the frog is described on p. 330. *t.*, Testis (that of the rabbit is not lettered); *ur.*, ureter; *v.d.*, vas deferens (Wolffian duct); *v eff.*, vasa efferentia.

side farther back than that on the right. Like those of the

Excretory and Reproductive Organs

dogfish and frog they consist of tubules, but they have no nephrostomes. It will be recalled that, whereas the kidney of the frog has no distinction of regions, and discharges solely by the Wolffian duct, that of the dogfish (like that of the newt) has a narrow anterior region, which takes little part in the secretion of the urine, and a larger hinder region, which is the main urinary organ and in the male possesses a duct of its own, the ureter. In the

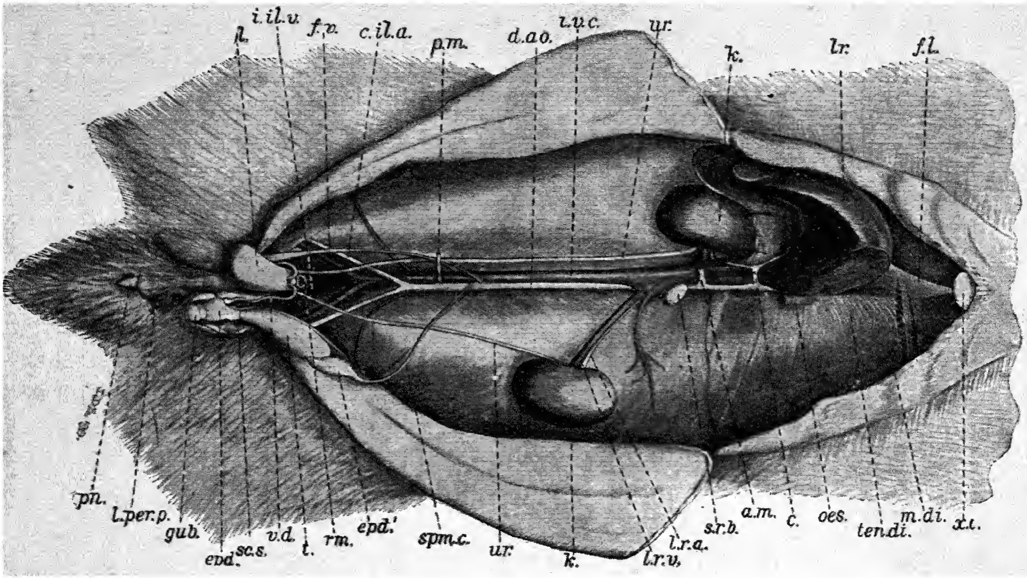


Fig. 191.—The abdominal cavity of a male rabbit, after removal of the alimentary canal.

a.m., *c.*, *c.il a.*, *d.ao.*, *f.v.*, *i.v.c.*, *i.il.v.*, *k.*, *l.r.a.*, *l.r.v.*, *p.m.*, *s.r.b.*, as in Fig. 194 : *bl.*, *epd.*, *epd'.*, *pn.*, *rm.*, *sc.s.*, *t.*, *ur.*, *vd.*, as in Fig. 192 ; *f.l.*, falciform ligament ; *gub.*, gubernaculum ; *lr.*, liver ; *l.per.p.*, left perineal pouch ; *m.di.*, *ten.di.*, muscular and tendinous parts of diaphragm ; *oes.*, œsophagus ; *spm.c.*, spermatic cord ; *x.c.*, xiphoid cartilage.

embryo of the rabbit a somewhat similar condition is found. A strip of kidney tissue—the mesonephros—lying in front of that which becomes the kidney of the adult, is served by a Wolffian duct. In the adult male the mesonephros becomes attached to the testis and the Wolffian duct becomes the vas deferens. In the female these structures are aborted. The adult kidneys of both sexes represent only the metanephros or hinder part of the embryonic kidney, which, instead of discharging through the Wolffian duct, has a duct of its own, the ureter. From the concavity or *hilus* the ureter runs back to open into the bladder. In the early stages of development this organ joins the rectum in a cloaca, but later the latter becomes divided, so that the urinary and generative organs discharge by an independent passage through the vulva or the penis. In front of each kidney lies a small, yellow, suprarenal gland. The testes are a pair of ovoid bodies which arise in the course of development on the dorsal wall of the peritoneal cavity near the kidney, but later become free and pass backward into two pouches of the body-wall at the sides of the penis known as the scrotal sacs. Each testis remains connected with its original position by a *spermatic cord*, which consists of connective tissue with an artery and vein. In passing backwards it carries with it the mesonephros, which in the adult may be seen as the *epididymis*, lying along the side of the testis and enlarged at the front and hind ends into a *caput* and *cauda* respectively. The cauda epididymidis is connected to the scrotal sac by a short, elastic cord known as the *gubernaculum*. Each epididymis consists of a mass of twisted tubules joining into a single, much-coiled tube which becomes continuous at the cauda with the vas deferens (or *ductus deferens*). This passes forwards out of the scrotal sac, curves over the ureter, and passes backwards again to open into a small median sac known as the *uterus masculinus*, which lies above the neck of the bladder within the pelvic girdle. The uterus masculinus opens into the neck of the bladder, which is known after their junction as the *urinogenital canal or urethra*, and passes backwards into the penis, at the end of which it opens. Beside the uterus masculinus lie the *prostate glands* which pass their secretion

into the urethra, and behind the prostate are *Cowper's glands*. The penis is situated behind the symphysis pubis and in front of the anus. It has spongy, vascular walls and is invested by a loose sheath of skin, the *foreskin or prepuce*. The ovaries are small oval bodies attached behind the kidneys to the dorsal abdominal wall, and show on their

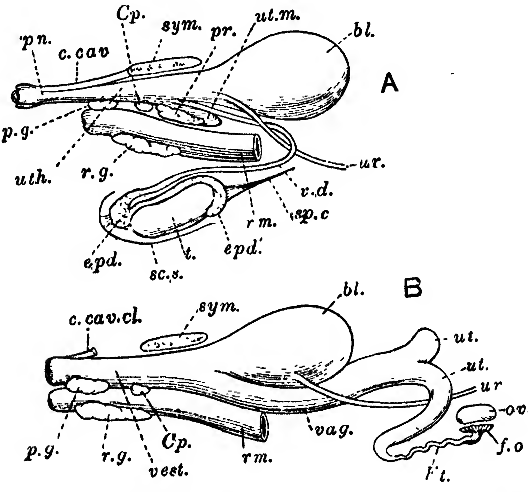


FIG. 192.—The reproductive organs of the rabbit. *A*, Male; *B*, female. In each case the dissection is made from the left side, the animal lying on its back.

bl., Bladder; *c cav.*, corpus cavernosum; *c cav.cl.*, corpus cavernosum of the clitoris; *Cp.*, Cowper's gland; *epd.*, cauda epididymidis; *epd'.*, caput epididymidis; *F.t.*, Fallopian tube; *f.o.*, fimbriated opening of the same; *ov.*, ovary; *p.g.*, perineal gland; *pn.*, penis; *pr.*, prostate; *r.g.*, rectal gland; *rm.*, rectum; *sc.s.*, scrotal sac; *sp.c.*, spermatic cord (cut short); *sym.*, symphysis pubis; *t.*, testis; *ur.*, ureter; *ut.*, uterus; *ut.m.*, uterus masculinus; *uth.*, urethra; *v.d.*, vas deferens; *vag.*, vagina; *vest.*, vestibule.

surface small projections like blisters, known as *Graafian follicles*, each of which contains a microscopic ovum. The oviducts open into the abdominal cavity by wide, funnel-shaped *fimbriated openings* just outside the ovaries. When the ova are ripe the follicles burst and discharge the ova into the funnels which at that time extend over them. The first section of each duct is narrow and gently twisted

and is known as the *Fallopian tube*. It runs backwards and enlarges into the *uterus*, a vascular-walled structure which joins its fellow in the middle line in front of the bladder to form the *vagina*. This passes backwards within the pelvic girdle above the neck of the bladder, with which it presently unites to form the *urinogenital canal or vestibule*, which opens at the vulva. On its ventral wall lies the small, rod-like clitoris and on the dorsal wall two small Cowper's glands

During the spring and summer a periodical ripening of ova with their discharge, or *ovulation*, occurs at intervals of about a month. Coition takes place during one of these periods, shortly before ovulation. The spermatozoa travel up the oviducts and fertilisation takes place at the upper ends of the latter. The ova pass down the oviducts, in which they segment. At the end of the third day they reach the uterus. Here at first they lie free. On the eighth day, however, they begin to become attached to the uterine wall, and in the course of the next few days there is formed in connection with each of them a special organ, known as the *placenta*, in which blood vessels derived from the mother and the developing young lie side by side in very close and extensive contact. Through the thin walls of the two sets of blood vessels interchange of fluid and gaseous contents takes place, and in this way the nutrition and respiration of the young is provided for until birth, which takes place at the end of a month from fertilisation. Animals in which, as in the rabbit, a great part of development takes place within the body of the mother, so that the young when they are born are beyond the need of a shell or similar covering, are said to be *viviparous*.

Blood Vessels: Heart.

The heart of the rabbit lies in the front part of the chest, enclosed in the thin pericardium, immediately behind the soft, pink thymus. It has no sinus venosus or conus arteriosus, but there are two ventricles as well as two auricles (atria), so that four chambers are present. Three venæ cavæ corresponding to those of the frog open directly into the right auricle (Fig. 193), and two pulmonary veins lead by a common opening into the left auricle. The opening from the right auricle into the right ventricle is guarded by a threefold

tricuspid valve (Plate VI), with chordæ tendineæ, and a similar twofold *mitral valve* guards the opening between the chambers of the left side. The two sides do not communicate with one another. From the front end of the right ventricle arises the pulmonary artery, and from the left ventricle the *aortic arch* arises in a similar position, but behind the pulmonary artery. The opening of each of these vessels is provided with three semilunar valves. The pulmonary artery divides to supply the two lungs, and the arteries to the head and arms arise from the arch of the

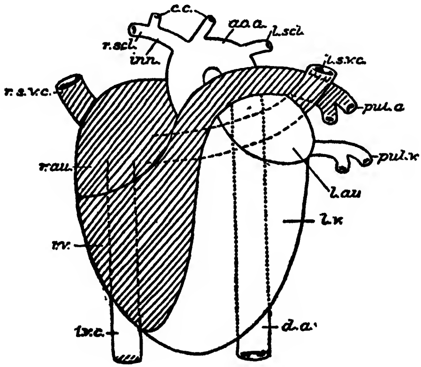


FIG. 193 —A diagram of the heart of the rabbit, in ventral view.
Lettering as in Fig. 189 and Plate VI.
Parts containing venous blood are shaded.

aorta, which afterwards supplies the trunk. In the beating of the heart, the auricles contract simultaneously, and the ventricles follow immediately afterwards ; then after a short pause the auricles start another contraction. The venous blood which reaches the right auricle from the capillaries of the body is driven by the auricular contraction into the right ventricle and thence in turn through the pulmonary artery to the lungs. Returning oxygenated to the left auricle it is driven into the left ventricle, and thence through the aorta to all parts of the body. There is thus a double circulation, as in the frog, but the separation of the ventricles and connection of the pulmonary artery with

one of them and the aorta with the other dispenses with the elaborate apparatus of the truncus arteriosus.

Arteries. The aortic arch bends over to the left and, as the dorsal aorta, passes backwards under the backbone through the chest and abdomen, till it becomes the small caudal artery. A ligamentous band, known as the *ductus arteriosus*, connects the aortic arch with the pulmonary artery, just before the bifurcation of the latter. At one stage in development this band is represented by an open tube (p. 330). In

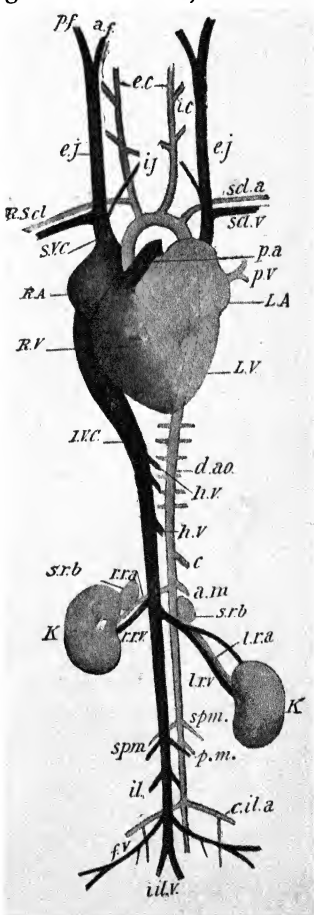


FIG. 194.—The circulatory system of the rabbit.—From Thomson.

(*a*) Letters to right—

- *e.c.* External carotid artery.
- *i.c.* Internal carotid artery.
- *e.j.* External jugular vein.
- *scl.a.* Subclavian artery.
- *scl.v.* Subclavian vein.
- *p.a.* Pulmonary artery (cut short).
- *p.v.* Pulmonary vein.
- *L.A.* Left auricle.
- *L.V.* Left ventricle.
- *d.ao.* Dorsal aorta.
- *h.v.* Hepatic veins.
- *c.* Cœliac artery.
- *a.m.* Anterior mesenteric artery.
- *s.r.b.* Suprarenal body.
- *l.r.a.* Left renal artery.
- *l.r.v.* Left renal vein.
- *K.* Kidney.
- *p.m.* Posterior mesenteric artery.
- *sp.m.* Spermatic artery (vein below).
- *c.il.a.* Common iliac artery.

(*b*) Letters to left—

- *p.f.* and *a.f.* Posterior and anterior facial veins.
- *e.j.* External jugular vein.
- *i.j.* Internal jugular vein.
- *R.Scl.* Right subclavian artery.
- *S.V.C* Superior vena cava.
- *R.A.* Right auricle.
- *R.V.* Right ventricle.
- *I.V.C.* Inferior vena cava.
- *r.r.a.* Right renal artery.
- *r.r.v.* Right renal vein.
- *s.r.b.* Suprarenal body.
- *spm.* Spermatic artery and vein.
- *il.* Ilio-lumbar vein.
- *f.v.* Femoral or external iliac vein.
- *i.il.v.* Internal iliac veins.

ts course the aorta gives off numerous arteries, of which the following are the most important: (1) The innominate, arising from the top of the aortic arch and dividing into the right subclavian and right common carotid, the latter passing up the neck and forking opposite the angle of the jaw into external and internal

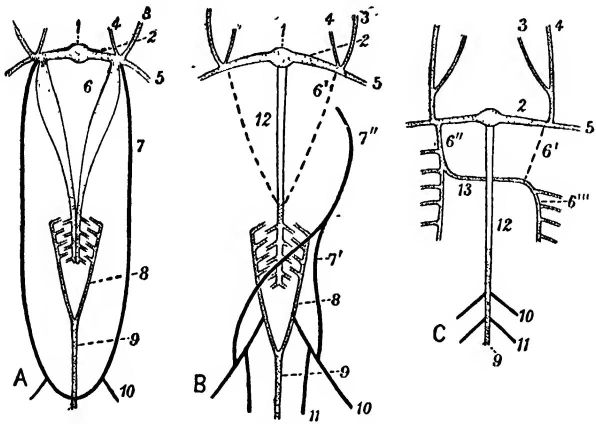


FIG. 195.—Diagrams of the venous system.

A, of a dogfish; *B*, of a frog; *C*, of a rabbit.

The main system in grey; the system of the lateral and anterior abdominal veins in black; the inferior vena cava in white. The hepatic portal system is omitted.

1, Entry to heart; 2, left superior vena cava or precaval or ductus Cuvieri; 3, left internal jugular or anterior cardinal; 4, left external jugular or inferior jugular, or sub-branchial; 5, left subclavian; 6, left posterior cardinal; 6′, position of same in a newt; in the frog the posterior cardinals are absent; in the rabbit the portion shown by dots is wanting; 6″, right azygos vein representing right posterior cardinal in a mammal; 6‴, left azygos vein; 7, left deep lateral vein, 7′, pelvic; 7″, anterior abdominal, representing both deep laterals fused; 8, renal portal; 9, caudal (wanting in frog); 10, external iliac or femoral; 11, internal iliac or hypogastric; 12, inferior vena cava or postcaval; 13, junction between azygos veins.

branches, (2) the left common carotid, arising from the aortic arch immediately beyond the innominate,[1] (3) the left subclavian, arising from the left side of the aortic arch, (4) the cœliac, which arises from the dorsal aorta shortly behind the diaphragm and divides into the hepatic and the lienogastric, (5) the anterior mesenteric, shortly behind

[1] Sometimes from the innominate itself.

the cœliac, (6) the renal arteries, (7) the genital arteries, (8) the small posterior mesenteric, (9) the common iliac arteries; these last arise just before the hip girdle and practically end the dorsal aorta, which after them is diminished to the caudal artery.

Veins. Each superior vena cava is formed by the union of a subclavian vein from the shoulder and fore-limb, an external jugular from the surface of the head, and an internal jugular from the brain. The right superior vena cava receives also an azygos vein from the walls of the chest. The external jugular is larger than the internal and lies nearer the surface in the neck. The inferior vena cava is a large median vessel which lies beside the dorsal aorta. It receives the following veins: (1) The internal iliacs or hypogastrics from the back of the thighs, (2) the external iliacs from the inside of the thighs, (3) the ilio-lumbars from the hinder part of the abdominal walls, (4) the genital veins, (5) the renal veins, (6) the large hepatic veins from the liver, through which organ it passes on its way to the heart. Blood from the stomach, intestines, pancreas, and spleen is carried to the liver by the portal vein, but there is no renal portal system. The general course of the circulation of the blood in the rabbit is shown in the table on p. 295.

Most of the lymphatic vessels are gathered up into a *thoracic duct* which opens into the left subclavian vein at its junction with the external jugular, but those of the right side of the head and neck and right fore-limb communicate with the venous system in the corresponding position on the right side. (The arrangement of the main lymphatic vessels of man, which is substantially the same as that of the rabbit, is shown in Fig. 196.)

Blood. The blood of the rabbit differs from that of the frog and dogfish in two important respects. (1) The red corpuscles, instead of being oval in outline and biconvex, with nuclei, are round and biconcave and have no nuclei. (2) The temperature of the blood, instead of rising and falling with that of the surrounding air or water, is almost constant at about 38° C. This is expressed by saying that the rabbit is a *warm-blooded* animal. The heat is produced, not in the blood, but in the solid tissues,

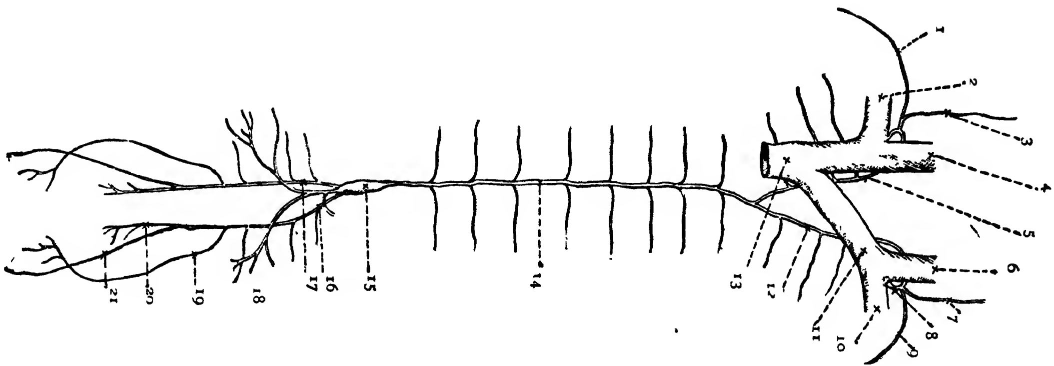
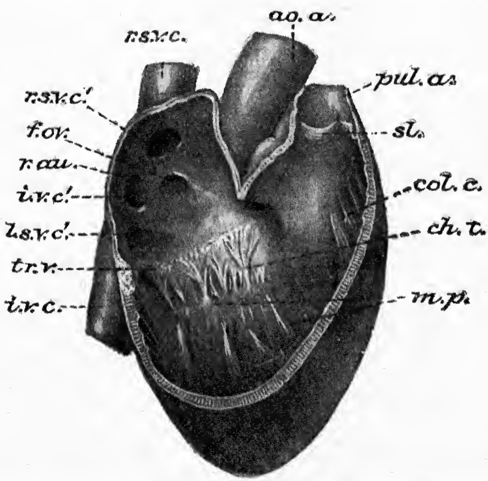


FIG. 196.—A diagram of the main lymph vessels, and of the branches of the superior vena cava of man.
—From Cunningham.

1, Right subclavian lymph-trunk; 2, right subclavian vein; 3, right jugular lymph-trunk; 4, right internal jugular vein; 5, bronch-mediastinal (lymph) duct, represented as connected below with the thoracic duct, as it sometimes is; 6, left internal jugular vein; 7, left jugular lymph-trunk; 8, thoracic duct; 9, left subclavian lymph-trunk; 10, left subclavian vein; 11, left innominate vein; 12, thoracic duct; 13, superior vena cava; 14, thoracic duct; 15, cisterna chyli; 16, left lumbar lymph-trunk; 17, right lumbar lymph-trunk; 18, intestinal lymph-vessels; 19, testicular lymph-vessels; 20, lymph-vessels from pelvis; 21, lymph-vessels from leg.

In man the left superior vena cava (innominate vein) joins that of the right side before entering the heart, forming thus a single superior vena cava.



ᑭLATE VI.—The heart of a rabbit, seen from the right side, after the removal of the outer wall of the right auricle and ventricle.

o.a., aortic arch; ***ch.t.***, chordæ tendineæ; ***col.c.***, columnæ carneæ; ***f.ov.***, fossa ovalis, the site of an opening through which in the embryo there passed into the left auricle blood returning to the heart by the inferior vena cava, much of which came from the placenta and was therefore arterial (p. 340); this blood was directed by a fold of the auricular wall known as the Eustachian valve, lying between the openings of the left superior vena cava and the inferior cava, traces of which fold remain in the adult heart; ***i.v.c.***, inferior vena cava; ***i.v.c.'***, internal opening of the same; ***l.s.v.c'.***, internal opening of left superior vena cava; ***m.p.***, musculi papillares; ***pul.a.***, pulmonary artery, cut open; ***r.au.***, wall of right auricle; ***r.s.v.c.***, right superior vena cava; ***r.s.v.c'.***, internal opening of the same; ***sl.***, semilunar valves; ***tr.v.***, tricuspid valve.

particularly in the glands and muscles, its appearance accompanying the activity of the tissue The circulation of the blood, however, keeps the temperature of different parts of the body nearly the same. The regulation of the temperature of the body as a whole is brought about by alteration in the production of heat and in the rate at which it is lost. The principal means of increasing the production of heat is the activity of the muscles. Shivering

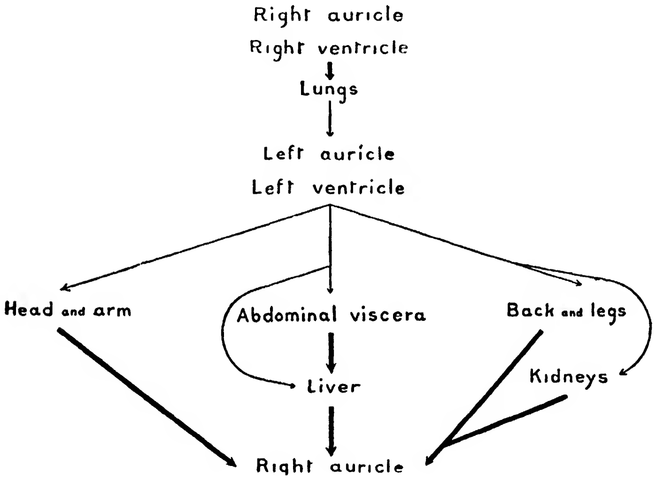


FIG. 197.—A diagram of the circulation of the blood in the rabbit. Thick lines indicate venous blood, narrow lines arterial blood.

is an example of this. Loss of heat is promoted by increased circulation in the skin and by sweating, which absorbs heat in the evaporation of the sweat.

Nervous System.

The brain of the rabbit resembles that of the frog in the main outlines of its structure, but there are considerable differences in detail between the two. The most conspicuous part is the cerebrum, which consists of two very large cerebral hemispheres divided by a deep cleft or *median fissure*, at the bottom of which they are joined by a bridge known as

the *corpus callosum*, composed of nerve fibres, nearly all of which run transversely. The surface of the hemispheres is almost smooth, but there can be seen on it faint indications of some of the furrows or *sulci* which in man are

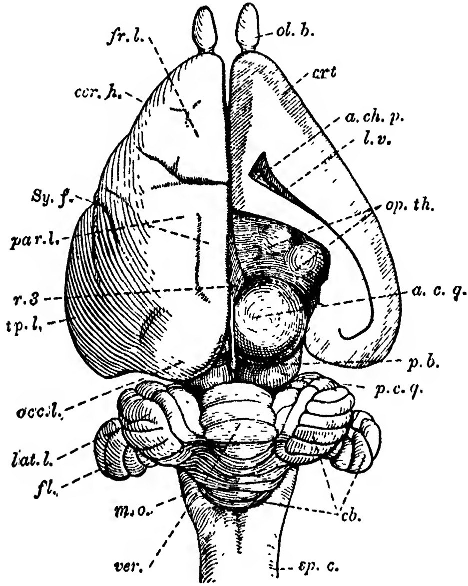


FIG. 198.—The brain of a rabbit, seen from above with part of the right cerebral hemisphere cut away.

a.c.q., Anterior corpus quadrigeminum; *a.ch.p.*, anterior choroid plexus; *cb.*, cerebellum; *cer.h.*, cerebral hemisphere; *crt.*, cortex, *fl.*, flocculus; *fr l.*, frontal lobe of cerebral hemisphere; *l.v.*, lateral ventricle; *lat.l.*, lateral lobe of cerebellum; *m.o.*, medulla oblongata; *occ.l.*, occipital lobe of cerebral hemisphere; *ol.b.*, olfactory bulb; *op.th.*, optic thalamus; *p.b.*, pineal body; *p.c.q.*, posterior corpus quadrigeminum; *par.l.*, parietal lobe of cerebral hemisphere; *r.*3, roof of third ventricle; *sp.c.*, spinal cord; *Sy.f.*, Sylvian fissure; *tp.l.*, temporal lobe of cerebral hemisphere; *ver.*, vermis.

deep and numerous and divide the surface into *convolutions*. At about the middle of its length each hemisphere is marked at the side by a shallow groove known as the *lateral or Sylvian fissure*, which separates a *temporal lobe* from the rest. On the under side a longitudinal *rhinal*

fissure marks off the *frontal* and *temporal lobes* from a region median to them known as the *rhinencephalon*, which consists of a *hippocampal lobe* behind and the *olfactory lobe* in front. The latter consists of the *olfactory tract* and the *olfactory bulb* which projects in front beyond

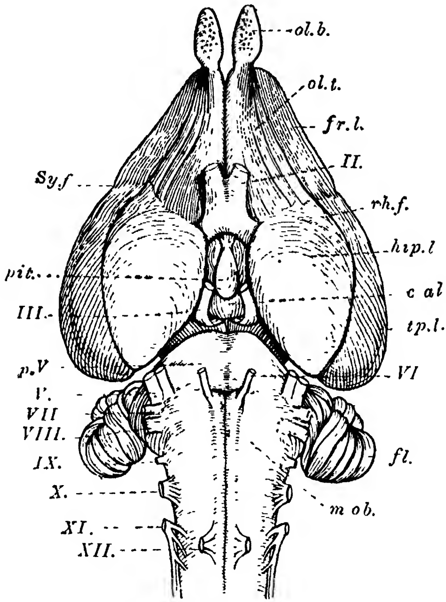


FIG. 199.—The brain of a rabbit from below.

c.al., Corpus albicans; *fl.*, flocculus; *fr.l.*, frontal lobe of the cerebral hemisphere, *hip.l.*, hippocampal lobe, *m ob.*, medulla oblongata; *ol.b.*, olfactory bulb; *ol.t.*, olfactory tract; *p.V.*, pons Varolii; *pit.*, pituitary body; *rh.f.*, rhinal fissure; *Sy.f.*, Sylvian fissure; *tp.l*, temporal lobe of the cerebral hemisphere; *II.–XII.*, roots of the cranial nerves.

the frontal lobe. The thalamencephalon is overhung and hidden by the cerebral hemispheres. Its thick sides form two large optic thalami, and from the hinder part of its thin roof the pineal stalk passes backwards to end in the pineal body between the hinder ends of the hemispheres. The infundibulum is a longitudinal

depression of the floor of the thalamencephalon, to which is attached the pituitary body. The latter, with the bottom of the infundibulum, is usually torn off in removing the brain from the skull, leaving a longitudinal slit which leads into the third ventricle or cavity of the thalamencephalon. A small, rounded, median swelling immediately behind the infundibulum is known as the *corpus mammillare or corpus albicans*. The midbrain is almost covered by the cerebral hemispheres. Each of its optic lobes is divided into two by a transverse furrow, so that four *corpora*

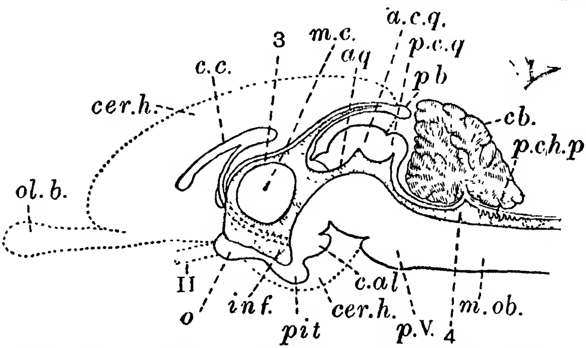


FIG. 200.—A semidiagrammatic median longitudinal section of the brain of a rabbit.

aq., aquæductus cerebri; *c.c.*, corpus callosum; *inf.*, infundibulum; *m.c.*, middle commissure, which connects the two optic thalami across the third ventricle; *o.c.*, optic chiasma; *p.ch.p.*, posterior choroid plexus; 3, 4, ventricles. Other lettering as in Figs 198, 199.

quadrigemina or colliculi arise. The crura cerebri are more prominent than in the frog. In the hind-brain, the cerebellum is very large and much-folded and consists of a median lobe or *vermis* and two *lateral lobes*, each of which bea s on its outer side a small lobe known as the *flocculus*. The lower side of the hind-brain is crossed by a wide, flat band of transverse fibres, the *pons Varolii*, which connects the two halves of the cerebellum. The medulla oblongata is broad in front and narrows gradually backwards to become the spinal cord. It is marked by a *ventral fissure* bordered by two longitudinal bands or *pyramids*.

There is no ventricle in the cerebellum, but small offsets

of the aquæductus cerebri enter the corpora quadrigemina. The third ventricle is deep, but very narrow, and is crossed by a large *middle commissure* which connects the optic thalami of the two sides.

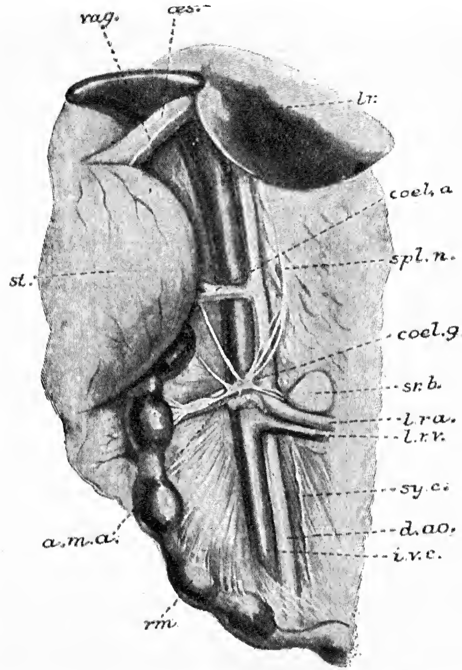


FIG. 201.—The solar plexus and neighbouring structures in a rabbit, exposed by opening the abdomen and drawing the stomach to the right.

a.m.a., Anterior mesenteric artery; *coel.a.*, cœliac artery; *coel.g.*, one of the cœliac ganglia; *d.ao.*, dorsal aorta; *i.v.c.*, inferior vena cava; *l.r.a.*, left renal artery (represented somewhat too large); *l.r.v.*, left renal vein; *lr.*, liver; *œs.*, œsophagus; *rm.*, rectum; *spl.n.*, left splanchnic nerve; *sr.b.*, suprarenal body; *st.*, stomach; *sy.c.*, sympathetic cord; *vag.*, left vagus.

The cranial nerves are twelve in number. The first ten resemble those of the frog in origin and function, but show certain differences; thus the olfactory nerves arise as a number of fine threads directly from the olfactory bulb and

pass at once through the openings of the cribriform plate at the front end of the cranium. The seventh nerve has no ophthalmic branch. The *eleventh or accessory nerve* arises from the side of the medulla and spinal cord by a number of roots, the first of which is just behind the vagus and the last at the level of the fifth spinal nerve. It supplies certain muscles of the neck. The *twelfth or hypoglossal nerve* also arises by several roots; these are situated on the ventral side of the medulla, outside the pyramid. Its course

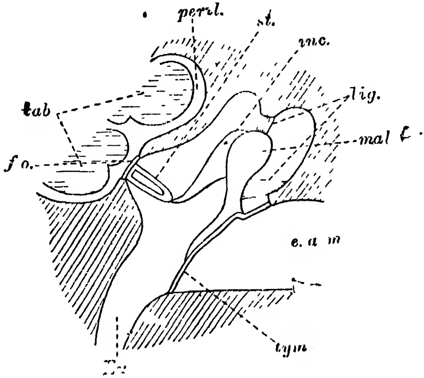


FIG. 202.—A diagram of the ear of a rabbit.

e.a.m., External auditory meatus; *Eu.*, Eustachian tube; *f.o.*, fenestra ovalis; *inc.*, incus; *lab.*, parts of the membranous labyrinth, containing endolymph; *lig.*, ligaments; *mal.*, malleus; *peril.*, perilymph; *st.*, stapes; *tym.*, tympanic membrane.

resembles that of the hypoglossal (first spinal) nerve of the frog. The spinal cord and nerves do not differ essentially from those of the frog. The sympathetic system is upon the same general plan as that of the frog. It has two ganglia on each side in the neck, twelve pairs in the thorax, and the same number in the abdomen. From the hinder thoracic ganglion there starts a *splanchnic nerve*, which passes backwards into the abdomen and ends with its fellow in a group of *cœliac ganglia* around the anterior mesenteric artery. These ganglia, with numerous nerves uniting and branching from them, constitute the *solar*

plexus (Fig. 201). A smaller plexus and ganglion of the same kind lie around the origin of the posterior mesenteric artery. A number of important nerves belonging to all these series are found in the neck. Among them are the following: (1) The hypoglossal, curving forwards round the angle of the jaw, with a backward branch, known as the *ramus descendens*, which passes to certain of the neck muscles; (2) the vagus, running backwards outside the carotid artery and giving off a *superior laryngeal* branch to the larynx, a *depressor* branch,[1] which arises near the superior laryngeal and passes backwards beside the main vagus, and a *recurrent* or *inferior laryngeal* branch, which loops forward round an artery and runs beside the trachea to the muscles of the larynx; behind this the vagus passes backwards along the œsophagus; (3) the *cervical sympathetic*, lying beside the vagus and depressor; (4) the spinal nerves, of which the third gives a *great auricular* branch to the ear and the fourth and fifth give off branches which join to form the *phrenic nerve* to the diaphragm. The vagus bears its vagus ganglion just before it gives off the superior laryngeal nerve, and the sympathetic bears near the ends of the neck its two cervical ganglia.

Sense Organs.

The sense organs do not differ from those of the frog enough to need special descriptions. Besides the structures we have mentioned in connection with the eye, there must be noticed the *lacrymal or tear glands*, situated above the outer corner of each eye, as well as Harderian glands corresponding to those of the frog (p. 81). There are no Harderian glands in man. The secretion of the eye glands flows over the conjunctiva and passes into the nose by the *nasal duct* at the inner angle of the eye. The structures of the outer and middle ear have been mentioned (p. 270). In the inner ear there is present a large, spiral division of the labyrinth, known as the cochlea, which contains the endings of those fibres of the auditory nerve which subserve the sense of

[1] This nerve, which runs to the heart, receives its name on account of its function. It conveys from the heart to the brain afferent impulses, as a result of which the central nervous system, acting through other nerves, lowers the pressure of the blood. In the thorax, the main vagus sends other branches to the heart.

burrows its way between the muscle plate and the notochord and forms from its wall the connective-tissue sheath of the notochord and nerve cord. This outgrowth is known as the *sclerotome*, the part which forms the muscles being known as the *myotome*. Lastly, a downgrowth from each dorsal division in the pharyngeal region gives rise to a gonad.

Habits of the Larva.

During the external and internal changes which we have traced, the larval *Amphioxus* swims freely in the sea, usually at a depth of a few fathoms from the surface. As its metamorphosis reaches completion, it sinks to the bottom and takes up the burrowing habits of the adult.

Frog: Segmentation.

The ovum of the frog has been described on p. 93. The first division of its cleavage (p. 110) forms two similar cells, each containing, like the ovum, an upper, black, pigmented portion and a lower,

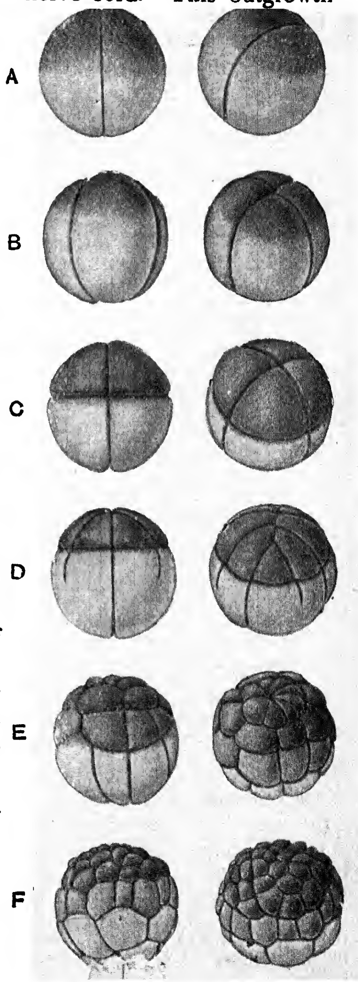


FIG. 215.—Stages in the cleavage of the frog's egg. Of each stage two views are given, one showing it from the side, the other obliquely from above. A–F show successively stages with two, four, eight, sixteen, thirty-two, and numerous blastomeres.

white, yolky portion. The second division is at right angles to the first and forms four similar blastomeres; the third division is horizontal and separates four small, pigmented, upper blastomeres from four large, yolky, lower blastomeres. By succeeding divisions sixteen and then thirty-two blastomeres arise, after which cleavage becomes irregular, the pigmented cells dividing more rapidly than the yolky. The final result is the formation of a blastula, in which the floor of the blastocœle is composed of large yolky cells and the roof of small pigmented cells. At the sides the upper cells merge gradually into the lower. The pigmented cells are the future epiblast, the yolk cells will give rise to the hypoblast, and both regions differ from the corresponding parts of the blastula of *Amphioxus* in being more than one cell deep, though the floor is much thicker than the roof. From this blastula a gastrula is formed, not by invagination, which would be im-

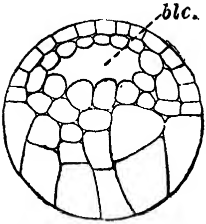


FIG. 216.—A vertical section of a frog's egg at the end of cleavage.

blc., Blastocœle.

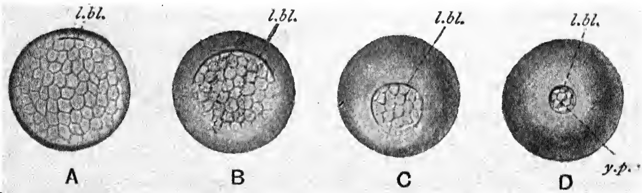


FIG. 217.—Stages in the gastrulation of the frog's egg. The egg is seen from the lower, white pole, which faces towards the future hind end of the animal.

l.bl., Lip of the blastophore; *y.p.*, yolk plug.

possible on account of the relative amount of the two layers, but by an overgrowing of the epiblast over the yolk cells.

Gastrulation. When this process begins, the black epiblast and the white yolk cells each form half the outer surface of the blastula, which floats with the black side uppermost. The epiblast grows downwards over the surface of the yolk cells, narrowing the exposed area of the latter. This extension of the epiblast is due to the division of the cells at the circumference of the white area in such a way as to sep[illegible] small epiblast cells outside from large

cells inside which belong to the primitive hypoblast or endoderm, the epiblast cells becoming pigmented as they form. Thus a skin of epiblast is, as it were, cut off from the surface of the yolk cells. This process is known as *epiboly*. If it took place all over the surface of the yolk cells the result would be the formation of a close skin of epiblast over a solid mass of hypoblast without an enteron. But on one side of the white surface, just below the edge of the epiblast, there appears a small, shallow, crescentic slit, convex towards the black area. Where the advancing epiblast reaches this, the process by which it is extending changes, being converted into multiplication of the cells of the black side of the slit, so that a fold or lip grows and projects over the yolk cells on the other side of the slit, and a narrow space is enclosed between the arched lip and the yolk cells. The side on which this happens is the future dorsal side of the animal. The space enclosed is the enteron. The cells on the outer side of the lip are of course epiblast, continuous with the rest of that layer. The cells of the inner side or lining of the lip are small hypoblast cells and form the roof of the enteron, its floor being formed by the large yolk cells over which the lip is growing. The lip is the upper edge of the blastopore, the rest of whose edge is as yet indefinite and represented by the limit of the advancing epiblast all round the egg. All this time the shape of

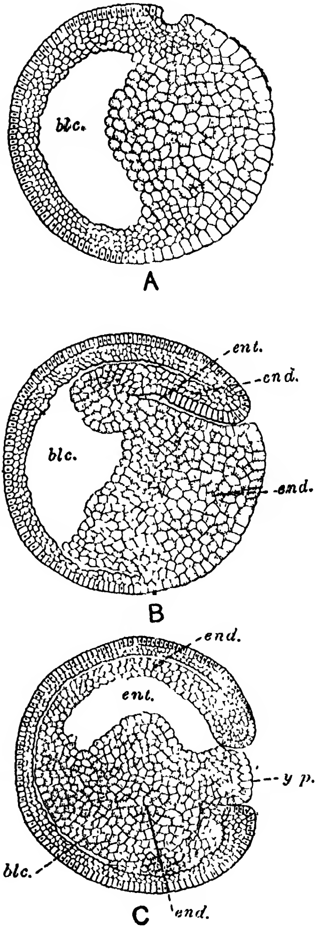


FIG. 218.—Sections of a frog's egg in successive stages of gastrulation. The sections are vertical and pass along the future longitudinal axis of the body, the hind end being to the right of the figure.

A, *B*, and *C* correspond roughly to *A*, *B*, and *D* of Fig. 217.

blc., Blastocœle; *end.*, yolky endoderm cells; *end'.*, small endoderm cells; *ent.*, gut; *y.p.*, yolk plug in blastopore.

the crescent is changing by its two ends lengthening and curving towards one another till at last they meet to form a circle. By that time the edge of the epiblast has reached this circle all round its circumference, so that all the yolk is covered except that within a circle area, the definitive blastopore, bordered by a continuous lip and filled by a *yolk plug* consisting of yolk cells which have not yet been covered. The lip continues to grow over the yolk plug, thus narrowing the blastopore. The narrowing, however, takes place not by equally rapid ingrowth of the lip all round, but by a faster growing together of the sides of the circle in its hinder part. At last the plug is covered and the blastopore is a mere slit. Then the middle part of this slit closes completely, its sides coming together, but leaving at its ends two small openings (Fig. 222). Of these the upper remains open, the last vestige of the blastopore, and becomes later the neurenteric canal (p. 308), while the lower, though it closes, leaves in its place a pit of ectoderm—the proctodæum—in which the anus eventually breaks through. Where the sides of the slit meet, between anus and neurenteric canal, there remains a seam in the form of a groove—the *primitive groove*—under which lies a band of cells—the *primitive streak*—in which epiblast, hypoblast. and mesoblast meet and fuse. During the later stages of this process an internal movement of the yolk cells has obliterated the blastocœle and enlarged the enteron, which was at first a mere slit, so that it becomes a spacious cavity, which communicates with the exterior by a slit between the dorsal side of the blastopore lip and the yolk plug.

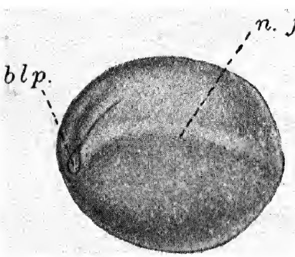


FIG. 219.—The embryo of a frog shortly after the completion of gastrulation, seen from the right side and somewhat from behind.

blp., Blastopore; *n.f.*, neural folds.

Formation of Mesoblast.

At the end of gastrulation the enteron is a large cavity with a very thick ventral wall composed of large yolk cells, many deep, and a thinner dorsal wall composed of smaller and fewer cells. From this wall, which is the primitive hypoblast, the mesoblast, or embryonic mesoderm, and the notochord have already begun to separate, leaving the hypoblast proper (Fig. 220).

The distinction between an outer layer of the primitive hypoblast, which is to separate as mesoblast and notochord, and an inner layer, which is to be hypoblast proper, begins in the lip of the blastopore and spreads thence over the primitive hypoblast. The way in which the blastopore lip overgrows the yolk cells from above causes the outer layer to form a broad band along the roof of the archenteron before it is distinguishable over the ventral mass of yolk cells.

The mesoblast arises by the splitting off of an outer layer of cells. The split starts on the dorsal surface on each side of the middle line, in the same position in which the pouches arise in *Amphioxus*, and spreads outwards around the thick ventral wall of the gut. For a time the mesoblast remains connected with the hypoblast along the mid-dorsal line, but presently it separates here also, leaving in the middle a cord of cells attached to the dorsal wall of the gut. This cord soon separates as the notochord. The mesoblast forms a sheet on each side of the gut, below which the two sheets soon meet, enclosing it completely

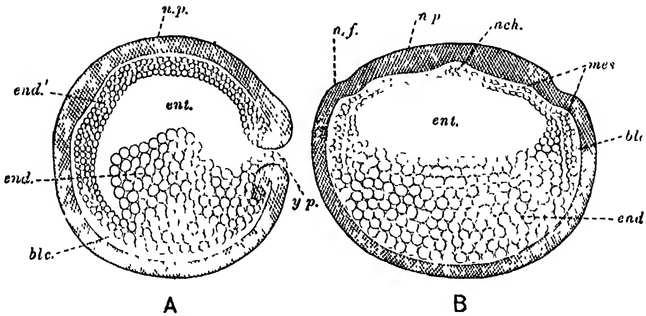


FIG. 220.—Sections of an embryo at about the stage of Fig. 219.
A, Vertical longitudinal; *B*, transverse
blc., Blastocœle; *end.*, yolk cells of endoderm; *end'.*, small cells of endoderm; *ent.*, gut; *mes.*, mesoderm; *n.f.*, neural fold; *n.p.*, neural plate; *nch.*, notochord; *y.p.*, yolk plug.

except in the mid-dorsal line, where the notochord lies (Fig. 220). On each side of this line the mesoblast is thicker than elsewhere, forming the *segmental plate*. A split, the rudiment of the cœlom, appears and separates an outer or somatic layer from an inner or splanchnic layer. This split does not extend far into the segmental plate, from which it soon disappears. The segmental plates now divide into a series of blocks or mesoblastic somites, separating from the *lateral plates*, which do not segment. The somites form from before backwards, but the head region is not segmented in the frog, though it is so in the embryo dogfish.

Meanwhile external changes have been taking place. The embryo at the end of gastrulation was still roughly

spherical, the blastopore marking the future hind end. In front of this the future dorsal surface flattens to form the pear-shaped neural plate, the edges of which thicken to form *neural folds*. These are continuous in front, and behind join the side lips of the blastopore. On either flank of the anterior end of the neural plate appears a thickening which becomes divided by a furrow into a *gill plate* and a *sense plate*. The neural folds become closer, rise up, bend over, and meet so as to enclose the neural canal, uniting first about the middle of their length (Figs. 222, 226, A). Since they enclose the blastopore vestige, the latter comes to lead from the gut to the neural canal and gives rise to a neurenteric canal, but this soon disappears. The neural canal separates from the epiblast above it, formed by the outer sides of the neural folds, whose inner sides become the wall of the neural canal. Before the folds have united in front, the open canal between them is divided into three swellings, the rudiments of the fore-, mid-, and hind-brains. It will be seen that in the frog, as in the lancelet, the central nervous system arises by the sinking in and folding off of a strip of the epidermis of the back. This process is found in all Chordata, and is of the highest importance in the drawing of comparisons between them and other animals. During the formation of the central nervous system the body has been elongating and other structures appearing. Below the blastopore, in the area which it occupied before its contraction, there appears, as we have seen, a pit known as the *proctodæum*, and an opening piercing through from this to the gut forms the anus. From anus to blastopore runs a slight groove, the *primitive groove*. Above it a knob grows out to form the tadpole's tail.

External Features of Embryo.

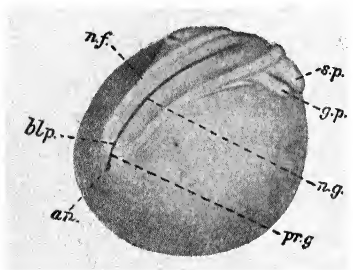


FIG. 221.—An embryo of the frog at a later stage.

an., Proctodæum (invagination which will form anus); *blp.*, last vestige of blastopore; *g.p.*, gill plate; *n.f.*, neural fold; *n.g.*, neural groove; *pr.g.*, primitive groove; *s.p.*, sense plate.

operculum, the gill-clefts close, and finally the tail shortens and is absorbed, and the metamorphosis is complete.

Germ Layers.

We have traced the internal development of the embryo up to the establishment of the three layers of the body of a triploblastic animal. Only an outline of the further development of these layers can be given. From the epiblast or embryonic ectoderm arise the epidermis, nervous system, sense organs, and lining of the mouth and cloacal opening; from the hypoblast or embryonic endoderm arise the lining of the greater part of the gut, the lungs, liver, pancreas, and thyroid, and the notochord; from the mesoblast or embryonic mesoderm

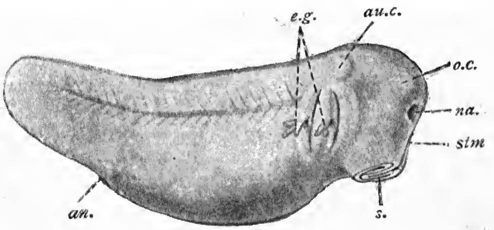


FIG. 224.—A frog embryo at the stage of hatching.

an., Proctodæum; ***au.c.***, slight swelling over the rudiment of the ear; ***e.g.***, external gills on gill arches; ***na.***, invagination to form nasal capsule; ***o.c.***, slight swelling over the rudiment of the eye; ***s.***, sucker; ***stm.***, stomodæum (invagination which will form the mouth).

arise the skeleton, connective tissues, muscles, vascular system, excretory organs, and generative organs. The skeletal tissues and unstriped muscle arise from a loose kind of mesoderm, known as *mesenchyme*, formed of cells budded off by the compact mass around the cœlom and perhaps also by the ectoderm and endoderm. The mass around the cœlom is known as *mesothelium*, and from it arise all the remaining mesodermal tissues.

Nervous System and Sense Organs.

The origin of the central nervous system has already been described. The dorsal roots of the nerves are formed as growths from the edges of the neural plate before the neural folds have met. The ventral roots arise later, as outgrowths from the side of the central nervous system, and those of the spinal

cord become connected with the corresponding dorsal roots. The formation of the olfactory organs has been mentioned. The posterior nares arise from the olfactory chambers as down-growths which break through into the mouth. The labyrinth of the ear is formed from the deeper layer of the epiblast as an ingrowth which forms a vesicle, but does not open to the exterior. It gradually takes on the shape of the labyrinth by the formation of septa which grow into it and divide it up. The eye has a more complicated origin. The retina and the pigmented epithelium arise from a pair of outgrowths of the fore-brain, known as *optic vesicles*, which grow out towards the sides of the head soon after the closure of the neural tube. Each takes on the form of a hollow bulb on a hollow stalk. The stalk gives rise to the optic nerve. The outer half of the bulb becomes thickened and then folded back into the inner half, as a hollow indiarubber ball may be folded when it has been punctured. The two-layered cup which thus arises is known as the *optic cup*. The thick layer which lines it is the retina, the thin layer on the side towards the stalk is the pigment layer. From the deeper layer of the epiblast there arises a thickening which projects into the mouth of the cup, separates from the epiblast, and becomes the lens, after passing through a stage in which it is a hollow vesicle.

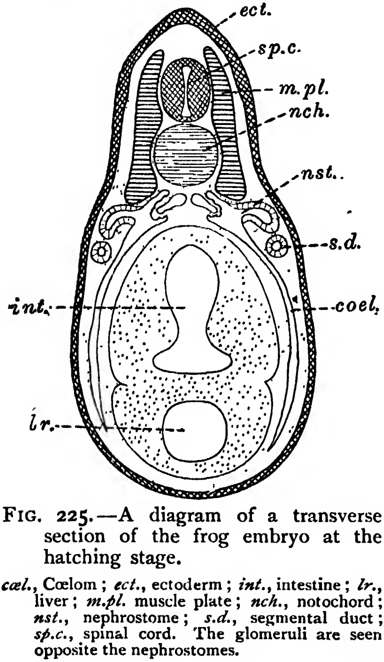


FIG. 225.—A diagram of a transverse section of the frog embryo at the hatching stage.

cœl., Cœlom; *ect.*, ectoderm; *int.*, intestine; *lr.*, liver; *m.pl.* muscle plate; *nch.*, notochord; *nst.*, nephrostome; *s.d.*, segmental duct; *sp.c.*, spinal cord. The glomeruli are seen opposite the nephrostomes.

Alimentary Canal.

The alimentary canal arises from three rudiments: the stomodæum (p. 321) or fore-gut, which is of epiblastic origin and forms the mouth; the mesenteron or mid-gut, which is hypoblastic and forms the greater part of the canal; and the epiblastic proctodæum (p. 320) or hind-gut, which forms the hind gut, which forms the cloacal opening. The pituitary body arises as an outgrowth from the roof of the mouth. The gill-slits are formed by outgrowths from the (hypoblastic) pharynx, which meet and perforate the skin. The first of them, corresponding to the spiracle of the dogfish, never opens, but forms the tympanic cavity and Eustachian tube. Between, in front of, and behind the clefts mesoblastic thickenings constitute the visceral arches, in which skeletal and vascular structures corresponding to those of the dogfish arise. The liver, pancreas, and lungs arise as ventral outgrowths from the gut. The thyroid body starts as a median longitudinal groove in the floor of the pharynx. This gives rise to a solid mass of cells which separates from the pharynx and divides into two. The intestine of the tadpole, when the yolk in its ventral wall has been absorbed, becomes for a time more coiled than that of the adult frog, probably in correspondence with the vegetable diet.

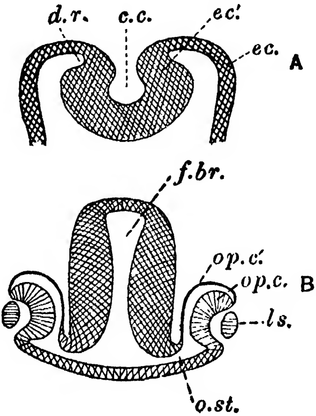


FIG. 226.—Diagrams to illustrate the formation of the central nervous system of the frog.

A, The folding off of the neural canal; *B*, transverse section of the fore-brain at the hatching stage.

c.c., Neural canal; *d.r.*, position in which dorsal root arises; *ec*, epiblast; *ec'*., infolding of the epiblast of the neural plate to form central nervous system; *f.br.*, fore-brain; *ls.*, lens; *op.c.*, inner wall of optic cup, which will form retina proper; *op.c'*., outer wall, which will form pigment layer; *o.st.*, stalk of optic vesicle.

We have seen (p. 319) that the body cavity or cœlom is developed as a split in the mesoblast sheets. The cells of the splanchnic and somatic layers which face towards this form

Mesoblastic Tissues.

the cœlomic epithelium. The greater part of the cœlom becomes the abdominal (pleuroperitoneal) cavity, surrounding the gut on all sides except in the mid-dorsal line, where the mesentery is left. A forward ventral prolongation of the cœlom becomes the pericardial cavity. The muscles of the gut arise from the splanchnic layer, the body muscles from the mesoblastic somites, which give rise to myotomes, though the regular arrangement of these is lost in the adult. The bulk of the skeleton is at first laid down in cartilage, which in places becomes converted into bone and in places is reinforced by membrane bones, as has been explained in the chapter on the skeleton of the adult. The first rudiment of the cranium has the form of a pair of curved longitudinal bars, the *trabeculæ*, lying below the brain, and joined behind to a pair of *parachordal plates* at the sides of the front end of the notochord, which projects into the floor of the tadpole's skull as it does into that of the dogfish. Between the trabeculæ is at first a space or "fossa," in which lies the pituitary body. These structures fuse with one another and with the cartilaginous nasal and auditory capsules, and upgrowths from them form the sides and eventually the roof of the cranium. The pituitary opening presently closes. The continuous palato-pterygo-quadrate bar of cartilage, which forms a part of the cartilage of the mandibular arch, is at first the only skeleton of the upper jaw. The hyoid apparatus of the adult is the remains of the skeleton of the hyoid and branchial arches of the tadpole.

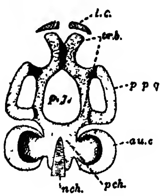


FIG. 227.—A diagram of the rudiment of the skull in a tadpole.

au.c., Auditory capsule; *l.c.*, labial cartilage, *nch.*, notochord; *p.f.*, pituitary fossa; *p.p.q.*, palato-pterygo-quadrate bar; *pch.*, parachordal plate; *tbr.*, trabecula.

Blood Vessels.

The heart appears some time before hatching. It is at first a straight tube, which arises below the pharynx. Subsequently the tube is thrown into an S shape and becomes divided by partitions into the several chambers. The endothelium or pavement epithelium which lines the heart arises by the rearrangement of some scattered cells which lie between the splanchnic layer

of mesoblast and the ventral hypoblast of the gut, and the muscular tissue is formed by a folding of the splanchnic layer itself. The space between the splanchnopleure and somatopleure in the region of the heart, which at this time is continuous with the rest of the cœlom, forms the pericardial cavity. The communication between the pericardial

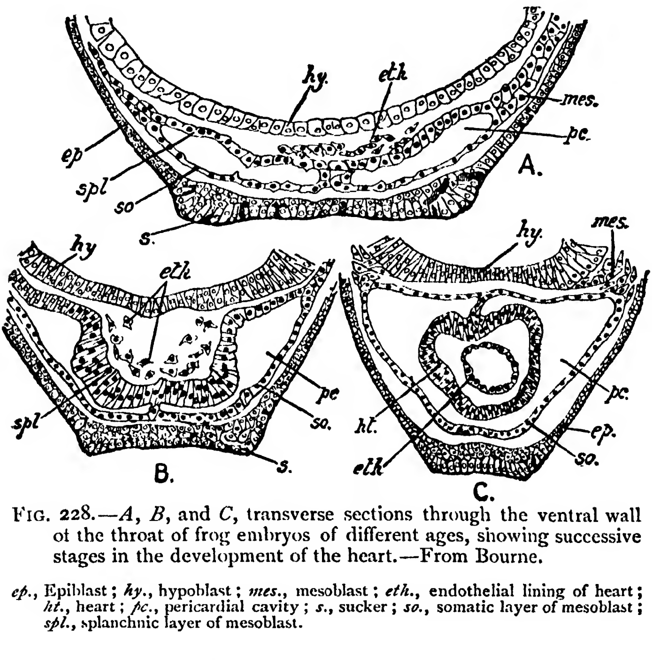


FIG. 228.—*A*, *B*, and *C*, transverse sections through the ventral wall of the throat of frog embryos of different ages, showing successive stages in the development of the heart.—From Bourne.

ep., Epiblast; *hy.*, hypoblast; *mes.*, mesoblast; *eth.*, endothelial lining of heart; *ht.*, heart; *pc.*, pericardial cavity; *s.*, sucker; *so.*, somatic layer of mesoblast; *spl.*, splanchnic layer of mesoblast.

and abdominal cavities is abolished by the formation of the great veins. The venous system is at first arranged on the same plan as in the dogfish, with two ductus Cuvieri and anterior and posterior cardinal veins. Subsequently the posterior cardinal veins disappear and are replaced by the inferior vena cava, the ductus Cuvieri becoming the superior venæ cavæ. The arterial system of the tadpole closely resembles that of a fish. The conus

arteriosus leads into a long ventral aorta, from the end of which arise four vessels to the branchial arches.[1] From the gill capillaries there arises in each arch an efferent vessel which discharges into a longitudinal suprabranchial

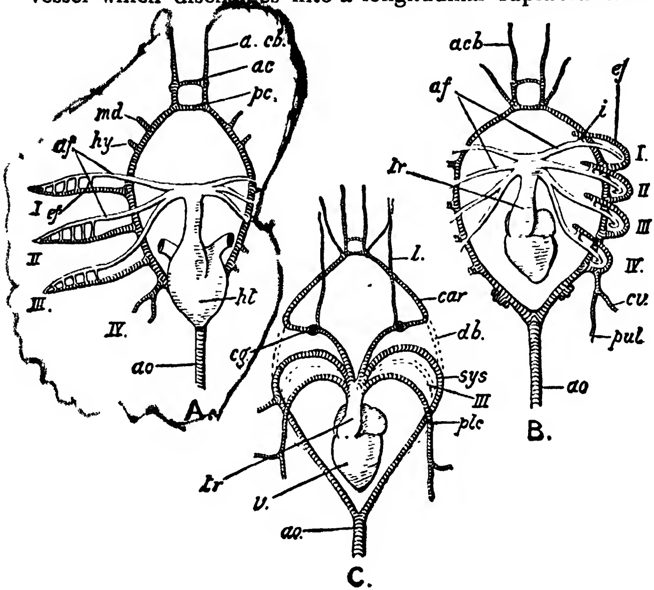


FIG. 229.—Diagrams of the heart and chief arteries of a tadpole.—From Bourne.

A, The vessels of a tadpole at the stage when three external gills are present; *B*, the arrangement when secondary gills are in use; *C*, the adult arrangement.

a.c., Anterior commissural vessel; *a.cb.*, anterior cerebral artery; *af.*, afferent branchial arteries; *ao.*, dorsal aorta; *car.*, carotid artery; *c.g.*, carotid gland; *cu.*, cutaneous artery; *d.b.*, ductus Botalli; *ef.*, efferent branchial arteries; *ht.*, heart; *hy.*, efferent hyoidean artery; *i.*, connecting vessel; *l.*, lingual artery; *md.*, efferent mandibular artery; *p.c.*, posterior commissural vessel; *pl.c.*, pulmo-cutaneous arch; *pul.*, pulmonary artery; *sys.*, systemic arch; *tr.*, truncus arteriosus; *v.*, ventricle; *I.-IV.*, branchial aortic arches.

artery. The two suprabranchial arteries join behind to form the dorsal aorta. In front they are continued as the common carotids. In the presence of a single efferent

[1] There are traces of similar vessels in the hyoid and mandibular arches.

vessel in each arch and of the two suprabranchial arteries the tadpole, while it differs from the dogfish, resembles certain other fishes. When the lungs ar formed, a vessel to supply each of them arises from the fourth efferent branchial vessel of the same side. Before the gills are lost, direct communication is established between the afferent and efferent vessels, so that when the gill capillaries disappear blood can pass direct from ventral to dorsal

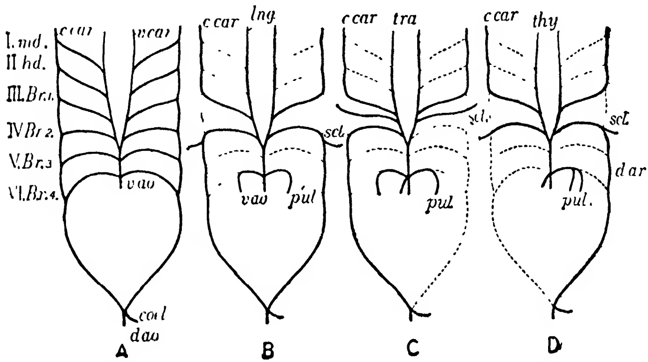


FIG. 230.—Diagrams showing how the arterial systems of adult vertebrates are related to that of the embryo.

A, Theoretically complete system of arches, not found in this form in any vertebrate adult or embryonic; *B*, the system of the adult frog; *C*, that of the adult bird; *D*, that of the adult mammal.

I.-VI., Visceral arches; *Br.*1–*Br.*4, branchial arches; *c.car.*, common (dorsal) carotid; *cœl.*, cœliac; *d.ao.*, dorsal aorta; *d.ar.*, ductus arteriosus; *hd.*, hyoid arch; *lng.*, lingual, representing ventral carotid; *md.*, mandibular arch; *pul.*, pulmonary; *scl.*, subclavian; *thy.*, small vessel to thyroid, representing ventral carotid of embryo; *tra.*, small vessel to trachea, representing ventral carotid; *v.ao.*, ventral aorta; *v.car.*, ventral carotid.

aorta through four continuous aortic arches. After the loss of the gill capillaries certain parts of the four arches disappear, while other parts persist and become the great arteries of the adult. The first branchial arch becomes the carotid. The portion of the suprabranchial artery which connected it with the arch behind it is usually obliterated, but sometimes there remains a trace of it known as the *ductus Botalli.* The second branchial arch becomes the systemic arch. The third branchial arch

disappears altogether. The fourth branchial arch becomes the pulmo-cutaneous. It loses its connection with the aorta save for a vestige in the form of a ligament in most adults, but sometimes, as always in the newt, an open connection persists, and is known as the *ductus arteriosus*.[1] We have seen (p. 291) that it is present also during the development of the rabbit, where a vestige remains in the adult.

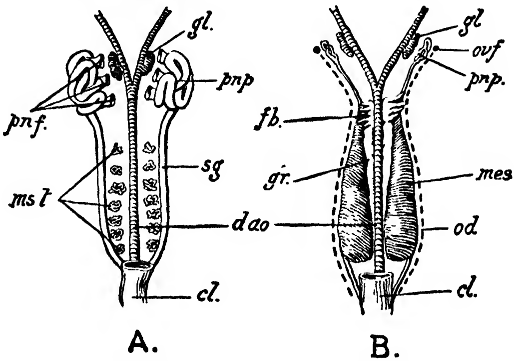


FIG. 231.—Diagrams of the development of the excretory system of the frog.—From Bourne.

A, The system of a tadpole about 12 mm. long, showing the pronephros and origin of the mesonephric tubules; *B*, the system at the end of metamorphosis. The broken line represents approximately the position of the strip of peritoneal epithelium which gives rise to the oviduct.

cl., Cloaca; *d.ao.*, dorsal aorta; *f.b.*, fat body; *gl.*, glomerulus; *g r.*, genital ridge; *mes.*, mesonephros; *ms.t.*, mesonephric tubules; *od.*, oviduct; *ovf.*, position of oviducal opening; *pn.f.*, pronephric funnels; *pnp.*, pronephros; *sg.*, segmental duct.

Excretory and Generative Organs.

The first rudiment of the excretory system appears some time before hatching as a longitudinal thickening of the somatic layer of mesoblast on each side of the body, at the front end of the peritoneal cavity, immediately below the myotomes. The front part of this thickening becomes converted into the head kidney or pronephros (p. 238), which consists of three twisted tubules, each opening by a funnel into the

[1] The terms *ductus Botalli* and *ductus arteriosus* are often used as equivalent to one another, each being applied to both of the little vessels which complete the carotid and pulmonary arches.

body cavity. Opposite the funnels a sacculated outgrowth of the splanchnic layer appears. It is known as the *glomerulus*[1] and becomes filled with blood from the systemic arch. The hinder part of the thickening which forms the pronephros becomes a longitudinal tube, the *segmental duct*, into which the pronephric tubules open at their outer ends. This duct grows backwards and at the time of hatching opens into the cloaca. Some time later the mid-kidney or mesonephros arises as a series of paired masses of cells along the inner sides of the segmental duct, behind the pronephros. This part of the duct becomes the Wolffian duct. Each of the masses in question develops into one of the tubules of the kidney, acquiring at one end an opening to the Wolffian duct and at the other a glomerulus and a nephrostome. Just before metamorphosis the pronephros and the front part of the segmental duct degenerate. The oviduct arises as a structure called the *Mullerian duct*, which is present in the late tadpole in both sexes, but degenerates in the male, leaving only a minute vestige. It is formed as a longitudinal tract of the peritoneal epithelium outside the kidneys, which becomes converted into a canal, the front part by being grooved and then closing in, the hinder part by hollowing out. Part of the groove does not close, but remains as the internal opening of the oviduct. The gonads are formed as thickenings of the cœlomic epithelium, one on either side of the mesentery, on the dorsal wall of the peritoneal cavity. No distinction between the sexes can be seen until the metamorphosis takes place.

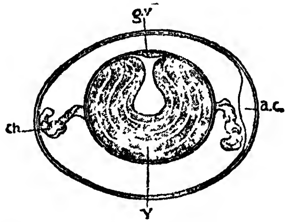


FIG. 232.—A diagrammatic section of the egg of a bird.—From Thomson.

a.c., Air chamber; *ch.*, twisted cords in the white known as "chalazæ"; *g.v.*, small patch of protoplasm comparatively free from yolk, in which lies the "germinal vesicle" or nucleus; *y.*, yolk, in alternate layers of yellow and white substance. The yolk is surrounded by the "white of egg." Note the two membranes underlying the shell and separating to enclose the air chamber.

[1] Better as the *glomus*, a glomerulus being a small glomus for a single tubule.

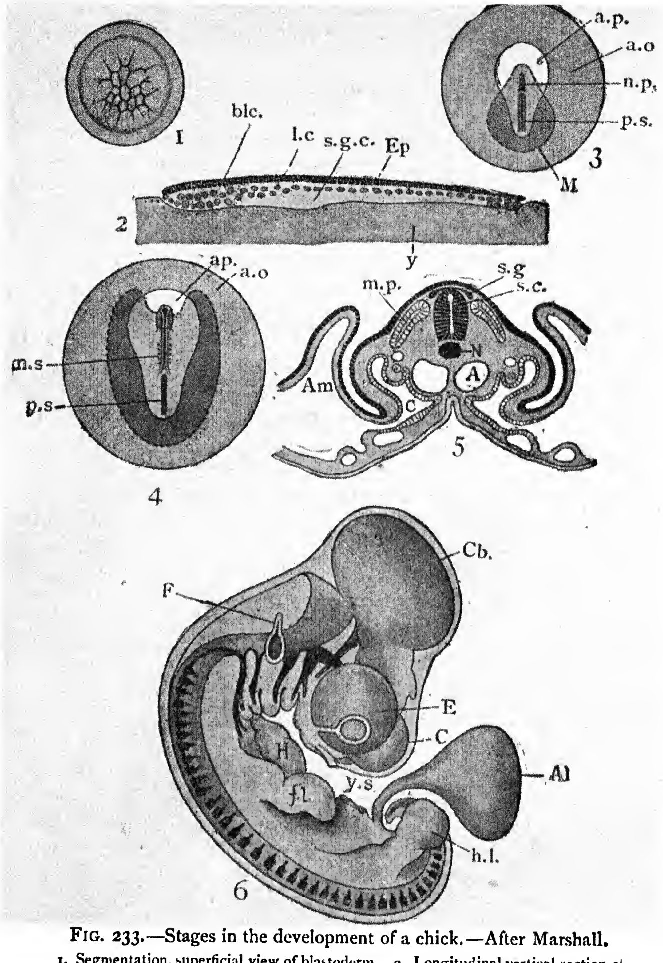


FIG. 233.—Stages in the development of a chick.—After Marshall.

1. Segmentation, superficial view of blastoderm. 2. Longitudinal vertical section of later blastoderm. *blc.*, blastocœle; *Ep.*, Epiblast; *l.c.*, lower layer of cells; *s.g.c.*, subgerminal cavity; *y.*, yolk. 3. Diagrammatic surface view, a little later; *a p.*, area pellucida; *a.o.*, area opaca; *n.p.*, neural groove; *p.s.*, primitive streak; *M.*, mesoblast spreading over yolk. 4. Diagrammatic surface view of later stage; *a.p.*, area pellucida; *a.o.*, area opaca; *m.s.*, mesoblast segments *p.s.*, primitive streak. The dark border shows the spreading of the mesoblast over the yolk. 5. Cross-section, later; *s.c.*, spinal cord; *s.g.*, rudiment of spinal ganglia; *N.*, notochord; *m.p.*, muscle plates; *A.*, aorta; *Am.*, amnion fold; *c.*, cœlom or pleuro-peritoneal cavity. 6. Embryo, *Cb.*, Cerebellum; *F.*, ear; *H.*, heart; *f l.*, fore-limb; *h.l.*, hind-limb; *y.s.*, stalk of cut-off yolk sac; *Al.*, allantois; *E.*, eye; *C.*, cerebrum.

Kinds of Segmentation. The difference in the segmentation of the ova of the lancelet and the frog is due to the presence in the latter of a considerable quantity of yolk or food material stored to provide for the nourishment of the embryo during the early stages of development. This yolk, lying on one side of the egg, hampers the relatively scanty protoplasm there, so that it divides more slowly. In the dogfish and in birds (Fig. 232) there is no food-procuring, larval stage of development, but the embryo is nourished within the egg until it has substantially the features of the adult. Here the yolk is still more plentiful, with the result that the portion of the egg in which it is stored never divides at all, but remains as an inert mass until it is surrounded by the growth of the small protoplasmic region or *germinal disc*, which lies originally at one pole containing the nucleus, and segments to form the cells of the embryo. The segmentation of the ovum of the lancelet is *complete or holoblastic* and almost *equal*; that of the ovum of the frog is holoblastic and *unequal*; in the dogfish and in birds it is *incomplete or meroblastic.*

Development of the Chick. Segmentation of the egg of a bird, such as the common fowl, begins with the formation across the germinal disc of a furrow which does not quite reach its edge. This is soon crossed by another furrow, and then more appear till the disc is divided into a mosaic of small irregular segments (Fig. 233, 1). Sections of the disc show that at the same time horizontal clefts are forming by which the segments become separated from the underlying yolk. By a further series of horizontal clefts the disc then becomes two or three cells deep. In that way, shortly before the laying of the egg, a cap of cells known as the *blastoderm* is formed. In this (Fig. 233, 2) the upper layer, the epiblast, is separated by a chink, the blastocœle, from a deeper mass of *lower layer cells* or primitive hypoblast, which will give rise to the hypoblast and mesoblast.[1] The two layers of a gastrula are now present, though they do not form a sac, and though they have arisen neither by invagination, as in the Lancelet, nor by overgrowth (epiboly), as in the frog, but by division

[1] A portion of the mesoblast arises from the epiblast of the primitive streak.

of a single layer of cells (*delamination*). The first rudiment of the enteron appears as a space formed by the separation of the lower layer from the underlying yolk, known as the *sub-germinal cavity*. In a surface view of the blastoderm (Fig. 233, 3), this gives rise to a central translucent *area pellucida*, round which is the *area opaca*, where the edge of the blastoderm rests on the yolk. The blastoderm grows over the yolk, the epiblast extending by the division of its cells, the lower layer partly in this way, partly by the addition of new cells cut off from the yolk. The blastopore is represented by a longitudinal strip in the hinder part of the blastoderm, where the epiblast is thicker than elsewhere and remains longer in continuity with the lower layer. This is the *primitive streak* (Fig. 233, 3), and is marked by a longitudinal *primitive groove*. The formation of the organs of the chick cannot be followed here. In broad outline it takes place in the same way as in the frog (compare Fig. 225 and No. 5 in Fig. 233). Something must be said, however, about the *folding off of the embryo* and the formation of the *embryonic membranes* which are found in reptiles, birds, and mammals. As development proceeds, furrows appear in the blastoderm of the area pellucida around a region which is forming the embryo, beginning in front and behind as *head and tail folds* and afterwards joining at the sides. These deepen, and pinch off the little embryo proper from the rest of the blastoderm, and the yolk around which the latter is growing. The splanchnopleure, folding inwards more rapidly than the somatopleure, comes to enclose the yolk in a sac—the *yolk sac*—separated from the somatopleure by a cœlomic space. As the embryo grows and absorbs the yolk it becomes larger than the yolk sac. The *amnion* is a peculiar membrane which envelops the embryo and arises in the following way. At a time when the splitting of the mesoblast into somatic and splanchnic layers has progressed some way outwards from the embryo over the yolk, there arise upward folds (*a.f.* in Fig. 234) parallel with the downward folds which formed the embryo, but consisting of somatopleure only. The folds on all sides of the embryo arch upwards and unite above, forming a dome over the embryo. When their tops unite, the inner limbs of the

folds form the *true amnion*, the outer limbs form the *false amnion*. The cavity bounded by the true amnion contains a fluid which bathes the outer surface of the embryo; that between the true and false amnions is lined by mesoblast and continuous with the cœlom of the embryo, and with that between the yolk sac and the overlying somatopleure. As the split between the layers spreads round the yolk sac, the outer layer it forms continues the false amnion, which finally encloses the sac. Meanwhile the folding off of the embryo has narrowed the connection between it and the rest of the blastoderm, so that the amniotic cavity encloses the embryo except in the region of this narrow *umbilical stalk* in the middle of the belly. While the amnion is being formed, a sac known as the *allantois* grows out from the hinder part of the gut of the embryo. This is lined with hypoblast and covered with splanchnic mesoblast, and projects into the body cavity. It grows down the umbilical stalk and spreads out between the true and false amnions. It becomes very vascular, and by its means the embryo breathes through the porous shell.

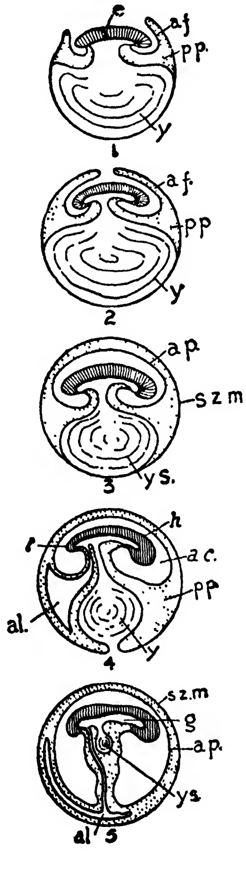


FIG. 234.—The origin of amnion and allantois.—After Balfour.

1. Rise of amniotic folds (*a.f.*) around embryo (*e*); *p p.*, pleuro-peritoneal cavity or cœlom; *y.*, yolk.
2. Further growth of amniotic folds (*a.f.*) over embryo and around yolk.
3. Fusion of amniotic folds above embryo; *a.p.*, amnion proper; *s.z.m.*, false amnion or subzonal membrane; *y.s.*, yolk sac.
4. Outgrowth of allantois (*al.*); amniotic cavity (*a.c.*); *h.*, head end; *t.*, tail end.
5. Complete enclosure and reduction of yolk sac (*y.s.*); *s.z.m.*, subzonal membrane; *a.p.*, amnion proper; *al.*, allantois; *g.*, gut of embryo.

The embryo chick has gill-clefts, and a system of arterial arches like that of the tadpole, but never shows any trace of gills. Finally, the beak pierces its way into an air chamber which exists at one end of the egg between the two membranes, and the animal begins to breathe by means of its lungs. The allantois now shrivels up (the yolk sac has already been absorbed) and the chick breaks its way out of the egg.

Development of Mammals.

In all mammals except the little group of Monotremata the egg is minute and undergoes total and nearly equal segmentation. Its development, however, is very different from that of the similar-looking egg of *Amphioxus*. Instead of producing a hollow sphere of cells which invaginates, segmentation nearly always results in a solid, spherical mass or "morula"; and there is never an invagination, though a stage comparable to the gastrula arises by the establishment of differences between layers of the cells, and possesses, in the primitive streak, the trace of a blastopore. The later course of development resembles in the main that of a bird, a yolk sac (which, however, contains no yolk), an amnion, and an allantois being formed. The details of the early stages and of the formation of the embryonic membranes differ a great deal in different mammals. In the Rabbit they take place as follows. The morula lies in the uterus, which it reached (p. 289) at the end of segmentation. It is covered by a single layer of cells which are rather smaller and more transparent than those within. This layer is known as the *trophoblast*, and will form a part of the epiblast—that part, namely, which covers the false amnion, but not the epiblast of the embryo proper or that which lines the amnion. It now begins to grow rapidly, so that it separates from the inner cells, except at one side, where they remain sticking to it, at first as a knob, which afterwards flattens out upon the inner side of the trophoblast, forming a circular patch, known as the *embryonal area*. This afterwards becomes oval, and will give rise to the embryo. The bladder-like structure which has thus arisen is known as the *blastodermic vesicle or blastocyst*. As it grows, its trophoblast cells stretch and become thinner and flatter. Meanwhile the cells of the embryonal area

begin to differentiate into two layers, an outer, columnar layer of epiblast, and an inner, flattened layer of primitive hypoblast. The hypoblast starts to grow round the blastocyst, lining the trophoblast beyond the embryonal epiblast. Over the latter, the trophoblast cells (here known

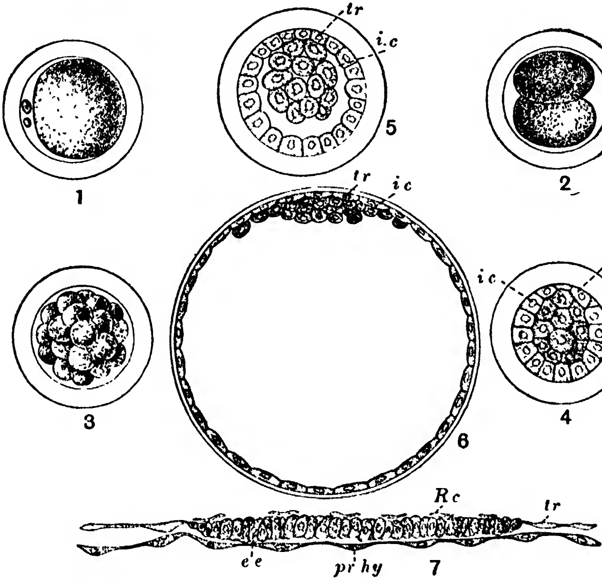


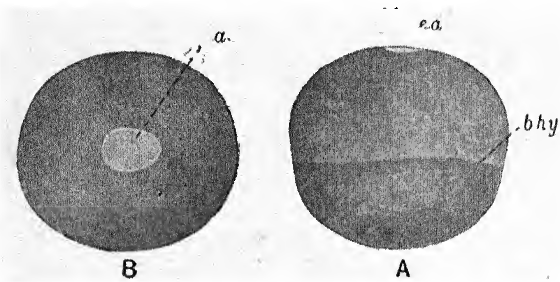
FIG. 235.—Early stages in the development of the Rabbit.—After various authors.

1, Ovum with polar bodies; 2, two-cell stage; 3, morula; 4, section of a later stage; 5, section of the young blastocyst; 6, section of an older blastocyst; 7, section of the embryonic area after differentiation of two layers.

e.e., Embryonal epiblast; *i.c.*, inner cells; *pr.hy.*, primitive hypoblast; *R.c.*, Rauber's cells; *tr.*, trophoblast.

as "cells of Rauber") become separated and disappear, leaving bare the embryonal epiblast, which at its edges becomes continuous with the trophoblast, so that the vesicle remains unbroken. The blastocyst is now practically in the condition of the early blastoderm of the chick, though instead of the immense mass of yolk of the bird's

egg there is only the fluid of the blastocyst, and the epiblast (including the trophoblast) already forms a complete vesicle. In the embryonal area primitive streak and groove, medullary folds, mesoblast, head and tail folds,



b.hy., Boundary of the hypoblast; *e.a.*, embryonal area.

amnion, and allantois now arise in succession. The mesoblast, however, never extends to the ventral side of the yolk sac, whose hypoblast is therefore, in that region, covered only by epiblast (trophoblast). Eventually the wall thus formed breaks up and disappears. Meanwhile, outgrowths or "villi" of the trophoblast burrow into the wall of the uterus. These are especially numerous over a

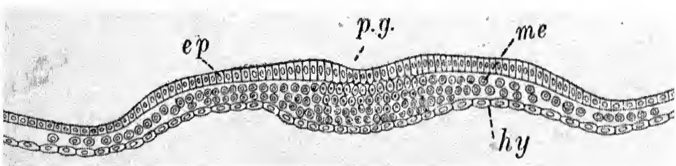


FIG. 237.—A transverse section through the embryonal area at about the stage of Fig. 236.

ep., Epiblast; *hy.*, hypoblast; *me.*, mesoblast; *p.g.*, primitive groove.

thickened, horseshoe-shaped patch of trophoblast which surrounds the hinder part of the embryo, in the region in which the placenta (p. 289) will arise. The early stages of the embryology of Man are imperfectly known, but it appears to belong to a type which resembles that of the

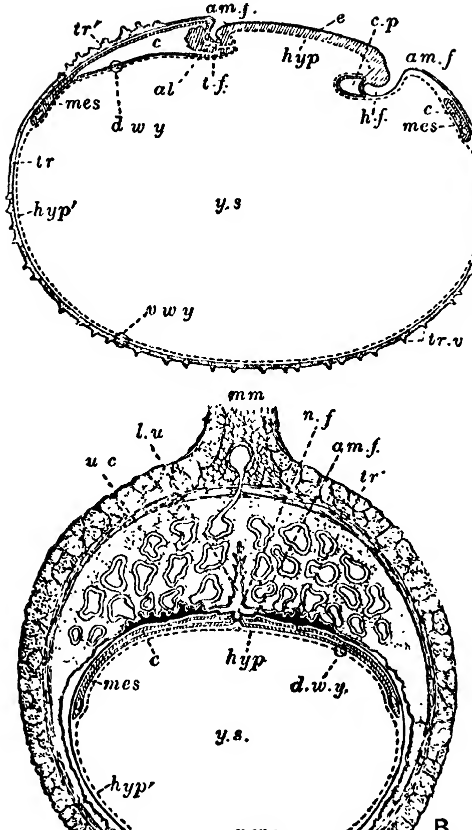


FIG. 238.—Sections of a rabbit embryo on the ninth day.—After various authors.

A, Longitudinal section through a blastocyst removed from the uterus; *B*, transverse section of the uterus and of a blastocyst *in situ*.—Partly after Marshall.

al., Allantois; *am.f.*, amnion fold; *c.* cœlom; *c.p.*, pericardium; *c.m.*, circular muscles of uterus; *d.w.y.*, dorsal wall of yolk sac; *e.*, embryo; *h.f.*, head fold; *hyp.*, hypoblast of embryo; *hyp'.*, hypoblast of yolk sac; *l.m.*, longitudinal muscles of uterus; *l.u.*, lumen of uterus; *mes.*, mesoblast; *mm.*, mesometrium of uterus; *n.f.*, neural folds; *t.f.*, tail fold; *tr.*, trophoblast (grey in *A*, black in *B*); *tr'.*, thickened region of same in which will arise placenta; *tr.v.*, villi of trophoblast; *u.c.*, uterine capillaries *v.w.y.*, ventral wall of yolk sac; *y.s.*, yolk sac.

chick less than the embryology of the Rabbit does. In it the trophoblast over the embryo does not disappear, and the amnion is formed very early, as a cavity in the embryonic ectoderm, which arises as a mass of cells, not as a layer. In the floor of this cavity the embryo is formed.

For a while the yolk sac of mammals forms a union with the uterine wall and serves for nutrition and respiration,

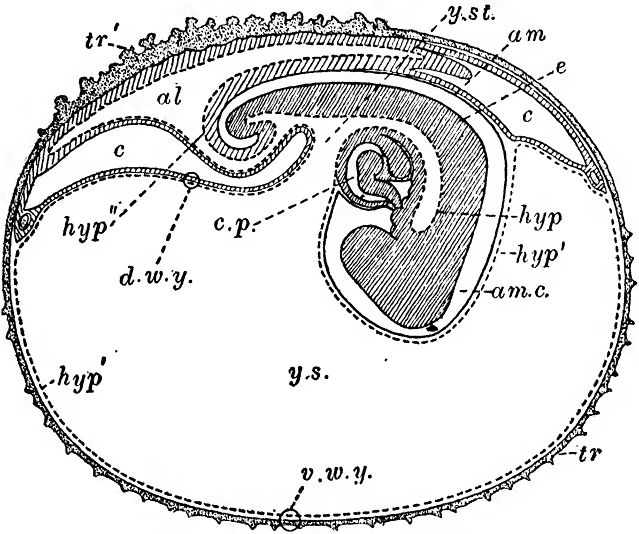


FIG. 239.—Longitudinal section of a rabbit embryo on the tenth day.

am., Amnion; *a.m.c.*, amniotic cavity; *hyp''.*, hypoblast of allantois; *y.st.*, stalk of yolk sac. Other letters as in Fig. 238.

but in this it is soon replaced by the allantois, which, as in the chick, spreads out under the false amnion or *subzonal membrane* and fuses with it. The organ thus formed is the placenta, and from it outgrowths penetrate into the uterine wall, expanding the original villi of the trophoblast and obtaining nourishment and exchanging gases with the maternal blood in lacunæ which are formed around them by the breakdown of blood vessels in the wall of the uterus. Thus, as in the chick, the blood in the allantoic vein is

arterial. The arrangement by which in the heart it is directed into the left auricle is described in the explanation of Plate VI. The navel of the adult marks the site of

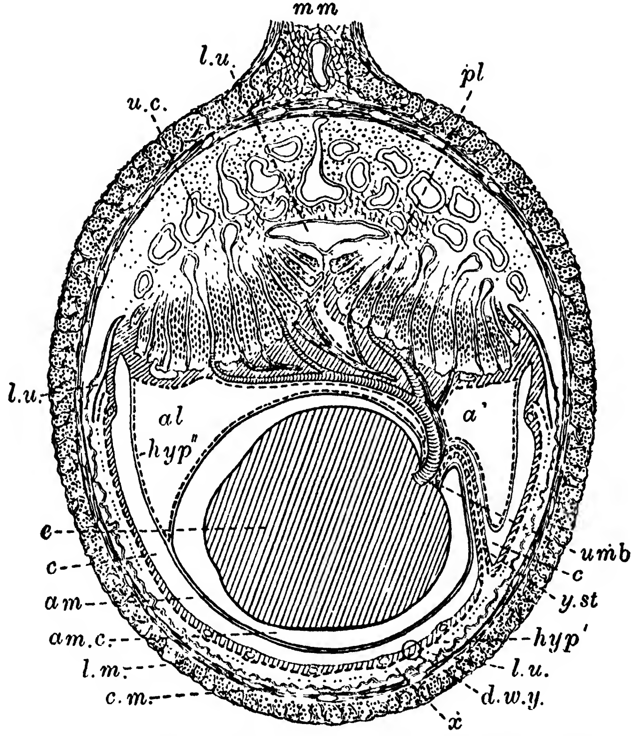


FIG. 240.—Transverse section of the uterus of a rabbit with an embryo of the nineteenth day.—Partly after Marshall. The placenta and membranes are now attached only by a narrow stalk to the embryo, which lies at its side.

pl., Placenta; *umb.*, umbilical stalk; *x.*, dotted line indicating position of vanished ventral wall of yolk sac. Other letters as in Figs. 238, 239

the *umbilical cord*, in which the stalk of the yolk sac and allantois and their blood vessels entered the body. The amnion is the "caul," and the placenta is shed as the "afterbirth."

The resemblance between the development of the minute, yolkless eggs of most mammals and that of the bird's egg, which is large and yolky, is a remarkable fact. It suggests that the ancestors of these mammals had yolky eggs as the Monotremata still have, that they acquired the habit of retaining them within the body, and that there the allantois, which in the bird's egg serves for the respiration of the embryo, enabled the mother to provide for the nourishment as well as for the respiration of her offspring, and with that the yolk disappeared. The Chordata whose embryology we have been studying exemplify well the several ways in which animals are nourished during their development. The lancelet obtains its own food as a larva. The frog during its early stages, and the bird throughout development, subsist upon yolk with which the ovum was stocked by the mother. Birds are provided also with nutriment (the "white") around the ovum in the shell. Mammals are nourished directly from the mother's body both before and after birth.

Von Baer's Law.

A comparison of the processes that have just been described shows two facts of importance. (1) They all have certain features in common. (2) The animals which are more alike as adults resemble one another longer in development. This generalisation is known as *von Baer's law*. All animals have at one stage a single nucleus. All Metazoa pass later through a gastrula stage of two layers only. When the Triploblastica acquire a third layer, Annelida, Arthropoda, and Mollusca have in common a process in which it starts as ventral bands, while in all Chordata it arises from the dorsal side of the primitive gut. All Chordata also have at one stage a notochord, a hollow dorsal nervous system formed by the folding of a neural plate, and gill-clefts. All Vertebrata have at a later stage a cartilaginous skeleton and a circulatory system like that of a fish. At a later stage still, the frog, bird, and mammal have pentadactyle limbs and the rudiments of lungs. The embryo of a rabbit is at one stage much like that of many other mammals, then it takes on the features of a rodent, finally it shows those of its own species. At the same time it must not be overlooked that von Baer's law holds

good only in a very general sense. The resemblance between the young stages of related animals is never exact and is often greatly obscured by disturbing factors, such as variations in the amount of yolk present or the precocious development of certain organs. Thus, for instance, the two-layered stages of the lancelet, frog, and chick (Figs. 208, 218, 233 (2)) are extremely unlike on account of differences in the amount of yolk they contain; and again amnion and allantois, which are peculiar to reptiles, birds, and mammals, are developed at an exceedingly early stage, when the embryo is only beginning to take on the features which are common to all chordate animals.

CHAPTER XVI

CLASSIFICATION AND EVOLUTION

Classification: Species.

THE animals that we have examined in the foregoing chapters have been chosen with a view to their serving, among other things, as examples of the principal kinds of creatures that constitute what is known as the Animal Kingdom. Explicitly or implicitly, the study of different objects of any kind must always proceed by a recognition of their resemblances and differences, but the number of different kinds of animals is so enormous that it is quite impossible to study them without arranging them in an orderly classification according to their degrees of likeness. We have seen that no two individual animals are wholly alike. The offspring of any parent are always unlike it and unlike one another. Even so-called "identical twins," whatever may be the case at their birth, become to some degree different by the different action of their surroundings upon them as they grow up. Heredity, in fact, does not produce absolute resemblance, but is qualified by what, using the term in its widest sense, we may call *variation*, whether it be due to an unlikeness in the offspring at birth or acquired by the impress of the surroundings during their lifetime. At the same time, the likeness between the offspring of any parent is, on the average, greater than their likeness to individuals descended from other parents, and in this fact we find the first degree of resemblance between animals. For practical purposes however, the resemblance between members of a family (in the ordinary sense of the word) is useless in classification, on account of the vast number of small divisions it gives and the impossibility of identi-

fying them. A more practicable basis is found in the fact that animals which are closely alike will breed together and give fertile offspring, whereas those which are less alike will not. Thus the offspring of two horses is fertile, but that of a horse and an ass is not, while breeding between horses and oxen is impossible. The primary groups of zoological classification consist of individuals which will breed together to give fertile offspring, or of which it is concluded from their likeness that they could do so. Such a group is known as a *species*. We have seen examples of the kind of differences which separate species in the case of the hares and rabbits (p. 259), of the crayfishes (p. 183), of the Hydras (p. 149), and of the *Entamœbæ* (p. 121). It is believed that all the members of a species are united by blood kinship; that is to say, that they are all in the long run the descendants of one pair or several related pairs of parents, so that their relationship is only an extension of that which exists between offspring of the same parents. Thus the resemblance between the members of a species depends on two things: (1) their community of descent, (2) their inability to weaken their likeness by interbreeding with unlike kinds of animals and thus acquiring new features. At the same time it must not be overlooked that upon the average, two members of a species differ in more respects than two children of one parent.

Higher Groups.

Species are grouped together by zoologists into divisions of a higher grade known as *genera*. A genus consists of several species which resemble one another closely, but its limits are determined by convenience only, and are not natural, like those of a species. To every species there is assigned a Latin name consisting of two words, of which the first denotes the genus to which the species belongs, while the second is peculiar to the species. Thus the generic name of the rabbits and hares is *Lepus*, the specific name of the rabbit is *cuniculus*, the common hare is *Lepus timidus*, the mountain hare *L. variabilis*. The names of the species of *Astacus*, *Hydra* and *Entamœba* have already been given. The Latin names of many species are arbitrary, and some are even misleading, but they have the advantage of providing a generally recognised, international nomenclature. In the

foregoing pages the Latin name of each species has been given. Above the genus are many divisions of the same nature, but higher rank. Genera are grouped into *families*, these into *orders*, orders into *classes*, classes into *phyla*, and in many cases it has been found necessary to institute additional grades of division, such as subclasses, subphyla, etc. The systematic position of the frog will serve as an instance of this arrangement. The frog is the Species *R. temporaria*, of the Genus *Rana*, Family *Ranidæ*, Order *Anura*, Class *Amphibia*, Subphylum *Vertebrata*, Phylum *Chordata*, Grade *Triploblastica*, and Subkingdom *Metazoa*. The following Table shows the main lines of the classification of the animal kingdom :—

I. Subkingdom PROTOZOA.

Animals whose bodies have not a cellular structure. Contains only the :

Phylum PROTOZOA.

a. Class RHIZOPODA.

Protozoa which move by means of pseudopodia.

e.g. *Amœba*, *Entamœba*, *Pelomyxa*.

b. Class FLAGELLATA.

Protozoa which move by means of flagella.

e.g. *Trypanosoma*, the sleeping-sickness parasite.

c. Class CILIATA.

Protozoa which move by means of cilia and have usually nuclei of two kinds.

e.g. *Paramecium*, *Vorticella*, *Carchesium*.

d. Class SPOROZOA.

Protozoa which are always internal parasites, form numerous spores, and have often no external organs of locomotion.

e.g. *Plasmodium*.

II. Subkingdom METAZOA.

Animals whose bodies are composed of cells.

A. Grade DIPLOBLASTICA.

Metazoa in whose bodies there are only two protoplasmic layers, ectoderm and endoderm. Contains only the :

Phylum Cœlenterata.

Radially symmetrical diploblastic animals.
e.g. *Hydra*, Jellyfishes, and Sea anemones.

B. Grade Triploblastica.

Metazoa in whose bodies a third layer, the mesoderm, lies between ectoderm and endoderm and usually contains spaces known as the hæmocœle and cœlom.

1. Phylum Annelida.

Bilaterally symmetrical, segmented Triploblastica, with a closed blood-vascular system, a well-developed cœlom, a double ventral nerve cord parting in front to enclose the gut, and a thin cuticle.

a. Class Oligochæta.

Annelida without parapodia, with setæ.
e.g. *Lumbricus.*

b. Class Polychæta.

Annelida with parapodia and numerous setæ.
e.g. *Arenicola.*

c. Class Hirudinea.

Annelida without parapodia or setæ, with two suckers, and with canalicular cœlom.
e.g. *Hirudo*, the Leech.

2. Phylum Arthropoda.

Bilaterally symmetrical, segmented Triploblastica, with an open blood-vascular system, a very restricted cœlom, a double ventral nerve cord parting in front to enclose the gut, a thick cuticle, and paired, jointed limbs, some of which serve as jaws.

a. Class Crustacea.

Aquatic Arthropoda with two pairs of antennæ, and usually with gills.
e.g. *Astacus.*

b. Class HEXAPODA OR INSECTA.

Land Arthropoda without gills, but with internal air tubes for breathing, with one pair of antennæ, three pairs of legs, and usually two pairs of wings.

e.g., *Periplaneta.*

c. Class MYRIAPODA.

Land Arthropoda without gills but with internal air tubes, with one pair of antennæ, numerous pairs of legs, and no wings.

Centipedes and Millipedes.

d. Class ARACHNIDA.

For the most part land Arthropoda without gills, but with internal air spaces; and all without antennæ and with four pairs of legs.

Scorpions, Spiders, Mites, and Ticks.

7. Phylum CHORDATA.

Bilaterally symmetrical, usually segmented Triploblastica, with a closed blood-vascular system, a spacious cœlom, a hollow, dorsal central nervous system, a notochord, and gill-clefts.

α. Subphylum CEPHALOCHORDA.

Chordata with a notochord which runs from end to end of the body and lasts throughout life, an atrium, and very numerous gill-slits provided with tongue-bars; without definite brain, heart, limbs, or skeleton of bone or cartilage.

e.g. *Amphioxus.*

β. Subphylum VERTEBRATA.

Chordata in which the notochord does not reach the front of the head and is usually reduced or lost in the adult, without atrium, with few gill-slits, which are without tongue-bars and are often lost in the adult; with well-developed brain, heart, usually two pairs of limbs, and always an internal skeleton of bone or cartilage.

a. Class PISCES.

Cold-blooded Vertebrata with paired fins, bony scales, rays in the median fins, persistent gill-clefts, and no lungs, amnion, or allantois.

i. Sub-class ELASMOBRANCHII.

Cartilaginous fishes without an air-bladder.

e.g. *Scyllium*.

ii. Sub-class TELEOSTOMI.

Fishes with bone in the skeleton, an air-bladder not used as a lung, and no internal nares.

e.g. *Salmo*.

b. Class AMPHIBIA.

Cold-blooded Vertebrata with pentadactyle limbs, usually no scales, no rays in median fins, lungs, shell-less eggs, no amnion or allantois, and a tadpole larva with gill-clefts which are usually lost in the adult.

i. Order URODELA.

Amphibians with short limbs, and with a tail.

e.g. *Molge*, the Newt.

ii. Order ANURA.

Amphibians with stout bodies, long legs, and no tail.

e.g. *Rana*.

c. Class REPTILIA.

Cold-blooded Vertebrata with pentadactyle limbs, horny scales, no median fins, lungs, large, heavily yolked eggs laid in calcareous shells, no larva, an amnion and an allantois in the embryo, and the gill-clefts never functional.

d. Class AVES

Warm-blooded Vertebrata with pentadactyle limbs, of which the first pair are wings, feathers and on the legs horny scales, no median fins, lungs, large, heavily yolked eggs laid in calcareous shells, no larva, an amnion and an allantois in the embryo, and the gill-clefts never functional.

Birds.

e. Class MAMMALIA.

Warm-blooded Vertebrata with pentadactyle limbs, hairs, but no scales, median fins only in some whales, where they have no rays, lungs, eggs almost always minute, developing within the mother, milk-glands, no larva, an amnion and an allantois in the embryo, and the gill-clefts never functional.

e.g. *Lepus*.

The Meaning of Differences between Animals.

The discovery of differences such as those with which we have just been concerned is one of the main tasks of zoology, but it is not the whole task. An essential part of the science is the attempt to explain the differences which it finds. The unlikeness between the several kinds of animals is not explained by the fact that in most, if not in all, cases it corresponds to differences in their lives. A full explanation of it can only be reached when we know both how it has arisen and why it is connected with different modes of life.

Evolution: "Proofs."

From the earliest days of the science two theories have been current as to the origin of the differences between the several kinds of animals. One contents itself with the statement that each species has come into being independently by a process of *special creation*, whose method it does not attempt to explain. The other alleges that every species has sprung from some other species that was in existence before it, by a process known as *evolution*, which arises from the existence of differences between parents and their offspring, and that the differences upon which the zoologist founds genera and higher groups are due to the unlikeness between species being increased by the same process. Evolution is an alteration of the average characters, either of the whole of a species or of a certain group of its members, from generation to generation in a constant manner, by which they become so different from what they were at first that a new species arises. This theory is now held by all zoologists. It is based upon several classes of evidence.

(1) It is supported by the facts upon which *classification* is based. Species, genera, families, orders, etc., are like the branches of a genealogical tree, and when they are arranged as such suggest strongly that they have arisen by modification each from the preceding grade. By the alteration in different directions of groups of members of a single species, the several species of a genus would arise. As each of these pursued its own line of evolution it would become more unlike its congeners until it reached the rank of a genus, by which time it would generally have given rise to species of its own, and so forth. Every attempt to classify animals results in an arrangement which to some extent suggests the evolution of its members, but in modern zoology classifications are expressly so constructed as to show what are believed to have been the lines of evolution which animals have followed. Each of the groups of such a classification represents an original species, from which all the subdivisions of the group are supposed to have arisen by descent with modification in various directions. As an illustration of this, the several groups of the familiar animals which compose the class Mammalia may be arranged in the form of a genealogical tree as on page 352.

(2) The facts of *morphology* also support the theory of evolution. In our survey of a series of types of animals we have seen how organs which serve different functions are often built upon the same general plan, which is modified in different directions in the several instances. The hands of a frog, a rabbit, a man, a horse, and a bird are all built upon one plan, though the parts are of different shapes in the several cases. It is difficult to find any satisfactory explanation of this except evolution. Organs which are believed to have arisen by modification of identical organs in an ancestral animal are said to be *homologous*.[1] Thus the wings of a bird and a bat are

[1] The term is extended to include the case of members of a series in one individual, such as the nephridia of an earthworm or the limbs of a crayfish, which are said to be *serially homologous* because they are built upon the same plan, so that the repetition of structure which is seen in them appears to be of the same nature as the repetition of the structure of an ancestor in its descendants.

homologous with one another and with the hands of a man and the paddles of a whale. Organs which have the same function, but have arisen independently, are called *analogous*. The wings of a bird and an insect or the legs of a rabbit and

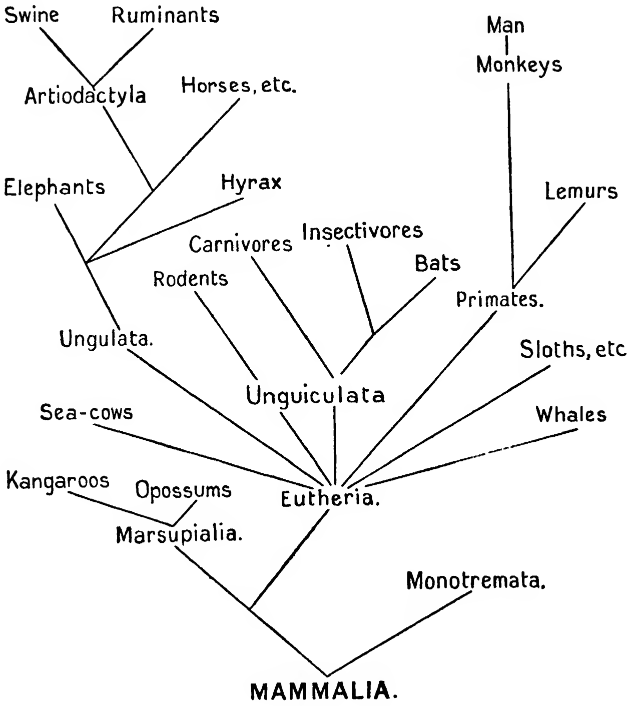


FIG. 241.—The classification of the Mammalia arranged in the form of a genealogical tree.

a crayfish are analogous. In the same class of evidence we may place the existence of *vestigial organs*, such as the ear muscles of man, which can only be satisfactorily explained on the supposition that they were functional in an ancestor. (3) The facts of *embryology* suggest evolution. We have seen that different animals pass through similar

stages, and that animals which are more alike resemble one another longer during development. All animals have at one stage no body nuclei, all Metazoa have at a later stage two layers only, all Vertebrata at a still later stage have gill-clefts and a notochord, all mammals at a later stage yet are five-fingered, and so forth. The simplest explanation of these facts is that (for reasons into which we cannot enter) development is a very rough recapitulation of evolution. This deduction from von Baer's law is known as the *theory of recapitulation.* (4) The facts of *distribution* are yet another support for the theory of evolution. It is

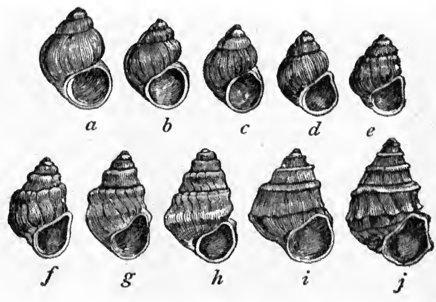


FIG. 242.—The gradual transition between *Paludina neumayri* (*a*), the oldest form, and *Paludina hœrnesi* (*j*).—From Neumayr.

found that the animal populations or *faunas* of various parts of the world differ, that this is the case even when the climates of the two regions are so similar that animals native in one will flourish in the other, as in England and New Zealand, and that the difference increases with the inaccessibility of one from the other. These facts have no explanation in the theory of special creation, but are easily explained on the supposition that the course of evolution has been different in the two cases owing to different histories in past geological times. (5) The facts of *palæozoology* (or the geological history of animals) are also in favour of evolution. It is clear that this is the only direction in which we could look for a complete *proof* of the theory, since all the other evidence does no more than

enable us to infer past history from present facts. Unfortunately, owing to what is known as the *imperfection of the geological record*, such complete proof is impossible. The unsuitability of the bodies of many animals for preservation owing to the absence of hard parts, the destruction of immense layers of rocks, and the small proportion of those which remain that can be examined, bring this about. But it is established that throughout geological

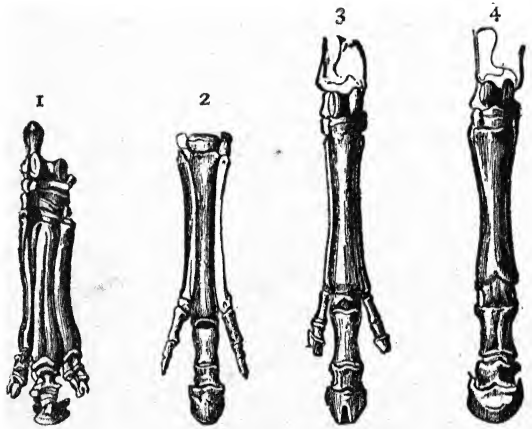


FIG. 243.—The bones of the foot of a horse compared with those of earlier members of its family.—After Neumayr.

1, Palæotherium, which appeared in the "Eocene" period of geology; 2, Anchitherium, which appeared in the following "Miocene" period; 3, Hippotherium, which appeared in the "Pliocene" period; 4, the modern horse. Note the continuous reduction of the side toes.

history there is a continual change in the types of animal life, leading up to those that exist at the present day, and in a few rare cases, particularly among Mollusca (Fig. 242), it is possible to trace fully the evolution of species, while in others, such as those of horses and of elephants, the origin of higher groups can be followed in the appearance of successive genera (Fig. 243).

As to how evolution has been brought about, there is a conflict of opinion. One theory supposes that the modifications which arise in each individual in the course

of its life, by its activity in response to the stimuli it receives from its surroundings or by the dwindling of certain of its organs from lack of use, are inherited in some degree by its offspring, and that the accumulation of such small modifications produces at length a different kind of animal. Thus, since it is known that one effect of cold upon a mammal is to increase the growth of its hair, the long fur of species which live in cold countries might be supposed to be due to the inherited effect of the climate. Again, the effect of use upon muscles is to increase their size, and in this way the great size of the wing muscles of birds of strong flight might be supposed to have been brought about in the course of many generations. On the other hand, the dwindling which is undoubtedly caused in the organs of individuals by disuse might in time bring about permanent degeneration, such, for instance, as that which is found in the eyes of animals which live in dark caves. This hypothesis is known as the *Lamarckian theory*, from the name of its greatest exponent. It is rejected by many zoologists at the present day on account of the lack of satisfactory evidence that modifications which are produced in the course of the life of an individual are transmitted by it to its offspring. Such modifications are known as *acquired characters*, and over the question of their inheritance discussion is still rife. The obstacles to belief in their transmissibility lie not only in the fact that numerous experiments and observations have hitherto failed to prove it beyond dispute, but also in the difficulty of conceiving any way in which modifications in distant parts of the body can so affect the germ-cells as to be handed on to the offspring.

The Mode of Evolution: Lamarckism.

Another hypothesis as to the way in which evolution is brought about is the *theory of natural selection*, known as *Darwinism* after the great naturalist by whom it was formulated. It supposes that the transformation of species is caused by the destruction by adverse circumstances of certain kinds of individuals in each generation before they can breed.[1] The result of this will be that the

Darwinism.

[1] Of course the eliminated individuals would not always be killed before they could breed. In some cases the reproductive period would merely be cut short so that the number of offspring was lessened.

next generation does not inherit the peculiar features of these individuals, which therefore gradually cease to appear in the species. Thus in a cold country those members of a species of mammals which had not thick fur would either die of cold or be so enfeebled that they could not compete with the rest in the struggle for food or mates, or in a herd of wild horses pursued by wolves the slowest would be killed, so that the next generation would be descended from those members of the species which were best clad or swiftest, as the case might be, and would of course inherit their peculiarities. The result of this process would be the selection by Nature of certain individuals to breed, just as a breeder selects sheep with thick wool or cattle with certain muscles well developed, and, breeding from these in preference to the rest, alters his breed of sheep or cattle.

Evolution by natural selection depends upon three factors: variation, the struggle for existence, and heredity. (1) We have seen that all animals are *variable*. It is true that there is great doubt of the heritability of the "acquired" variations[1] produced in the individual by the action of its surroundings at various stages of its existence, but there are other variations of whose inheritance there is no doubt. These are known as *germinal variations or mutations*, and are due to inborn tendencies which arise in the germs in some way which is not as yet understood. It is often urged that variations are too small to give an effective advantage in the struggle for existence, but mutations may be so great that in regard to them this difficulty does not exist. It may be that evolution takes place by the inheritance of such mutations alone. (2) The *struggle for existence* involves, not merely reaching a certain standard of fitness to cope with the surroundings, but a competition between individuals, because, while the offspring are always more numerous than the parents, the total number of individuals in the species does not as a rule increase, being already as many as the conditions of

[1] Small acquired variations due to the effect of the environment during growth are known as *fluctuations*. Thus one of a litter of young being better nourished in the womb may be larger and stronger, but will not transmit those qualities to its offspring.

food, enemies, etc., will allow. A pair of robins will produce ten or more young in a year, yet, since the number of robins does not increase, only two of these can survive. This is an exceptionally small death-rate. Many animals produce thousands of offspring: the blow-fly, for instance, gives rise to a progeny of 20,000. Now it is impossible to believe that the destruction which this involves is altogether haphazard. Some of the individuals will be feebler, or slower, or less cunning, or less protectively coloured, or less warmly clad than the rest, and it is certain that these will as a rule be the first to be destroyed, and that the survivors will generally be above the average of the rest in regard to the characters in which selection has taken place. (3) The alteration which is thus made in the average characters of the species will be maintained by the action of *heredity*. It is often alleged as an objection to the theory of evolution by natural selection that any large variation in a favourable direction, though it may lead to the survival of the individual in which it occurs, will nearly always be weakened in the next generation by what is known as the "swamping effect of intercrossing." That is to say, the exceptional individual will probably mate with an average member of the species and their offspring will be intermediate between them, and so in a few generations the favourable variation will have become so slight as to give no effective advantage in the struggle for existence. This difficulty, however, disappears in the light of discoveries which have been made by the students of heredity known as the *Mendelian* school, after the discoverer of the principles upon which they rely. We have already seen (p. 111) that, in many cases, when two individuals which differ in any respect breed together, their features do not blend, but the peculiarity of one parent is "dominant" in the offspring, while that of the other is latent or "recessive." For instance, the offspring of a wild grey rabbit and the black variety are all grey. Thus the dominant variety remains distinct and is not weakened by crossing. If, however, the offspring of such a cross be bred together, it will be found that the recessive variety has also not been extinguished, for on the average a quarter of the generation

will throw back to the recessive grandparent (in this case, the black rabbit). Thus it comes about that both varieties remain unimpaired within the species, and either will have its effect on the survival of individuals in successive generations.

The Organism in Evolution.

There are many difficulties in the way of the theory of evolution by natural selection; such, for instance, as the difficulty of explaining in this way the degeneration of useless organs, the rareness of variations of effective magnitude, the necessity for the simultaneous occurrence of many variations to originate or improve any organ, and so forth; but it is probable that in one form or another this theory is still held by the majority of zoologists. Some, however, unable to subscribe either to the Lamarckian or to the Darwinian theory, are compelled to fall back upon a belief in a directive force in the organism itself which compels it to change continuously in certain directions until it is extinguished by transgressing the limits which the conditions of life allow. Such a theory is in reality little more than an abandonment of the problem of adaptation. It does, however, emphasise a fact which upon other theories is apt to be forgotten, namely, that evolution is after all more the work of the organism than that of its environment. The organism alters, whether altogether spontaneously or as a result of its capacity to respond to changes in environment. The part of the environment is to decide which of the experiments of the organism are failures. By the two factors, the organism and its environment, each of the theories of evolution explains in its own way both the origin of species and their adaptation to such modes of life as are possible in their respective surroundings.

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Numbers in heavy type refer to pages with illustrations of the structure in question.